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Environmental Assessment of A Waste-to-Energy Process: Braintree Municipal Incinerator

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16. ABSTRACT

Midwest Research Institute conducted an array of field tests at the Braintree Municipal Incinerator facility in Braintree, Massachusetts, for the purpose of providing data on multimedia emissions to help determine adverse environmental impacts and pollution control technology needs. There are two incinerators at the Braintree facility; both are of the waterwall type and are designed to burn unprocessed mixed municipal refuse at a rate of 120 tons/day each. Air pollution control is provided by electrostatic precipitators.

Primary emphasis was placed on evaluating the air emissions. Analyses were carried out for criteria pollutants (particulates, NO_x, SO_2, CO, and hydrocarbons) as well as for potentially hazardous compounds such as polychlorinated biphenyls and polycyclic aromatic hydrocarbons. The Environmental Protection Agency-designed Source Assessment Sampling System train was also used as per the Environmental Protection Agency's Level 1 environmental assessment protocol. The data obtained were used to evaluate emissions in each effluent stream on the basis of existing standards or criteria and also through the use of the Environmental Protection Agency's recently devised Source Analysis Model (SAM-1A).

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Braintree Municipal Incinerator

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report documents the results of a total environmental assessment run on a waterwall incinerator in Braintree, Massachusetts. The information contained herein will be of interest to those involved in determining the environmental effects of waste-to-energy conversion and to those involved in developing control technology for these systems. Inquiries and comments regarding the report should be directed to the Fuels Technology Branch of the Energy Systems Environmental Control Division.

David G. Stephan
Director
Industrial Environmental Research
Laboratory-Cincinnati

ABSTRACT

Midwest Research Institute conducted an array of field tests at the Braintree Municipal Incinerator facility in Braintree, Massachusetts, for the purpose of providing data on multimedia emissions to help determine adverse environmental impacts and pollution control technology needs. There are two incinerators at the Braintree facility; both are of the waterwall type and are designed to burn unprocessed mixed municipal refuse at a rate of 120 tons/day each. Air pollution control is provided by electrostatic precipitators.

Primary emphasis was placed on evaluating the air emissions. Analyses were carried out for criteria pollutants (particulates, NO_x, SO_2, CO, and hydrocarbons) as well as for potentially hazardous compounds such as polychlorinated biphenyls and polycyclic aromatic hydrocarbons. The Environmental Protection Agency-designed Source Assessment Sampling System train was also used as per the Environmental Protection Agency's Level 1 environmental assessment protocol. The data obtained were used to evaluate emissions in each effluent stream on the basis of existing standards or criteria and also through the use of the Environmental Protection Agency's recently devised Source Analysis Model (SAM-1A).

SUMMARY

Field testing was carried out by Midwest Research Institute (MRI) at the Braintree Municipal Incinerator in Braintree, Massachusetts, in January 1978. The work was part of the Environmental Protection Agency (EPA) contract entitled "Environmental Assessment of Waste-to-Energy Processes" (EPA Contract No. 68-02-2166). The study was tailored to provide information on uncontrolled emissions to help determine future control needs. The test program and its results are presented in this report and summarized below.

The Braintree incinerator is a mass-burn unit firing municipal refuse collected from the surrounding communities. It is of the waterwall design with a design capacity of 120 tons of refuse per 24-hr period. Bottom ash retained on the traveling grate is discharged into a water quench trough prior to disposal. Air emissions are controlled by an electrostatic precipitator (ESP) for particulate removal. The collected ESP ash is slurried to the bottom ash quench trough and the quench water is discharged to the municipal sanitary sewer system.

Influent/effluent streams sampled for the environmental assessment included the following:

- Refuse feed;
- Bottom ash;
- Quench water;
- Air emissions preceding the ESP;
- Collected ESP ash; and
- Stack emissions (ESP outlet).

Sample analysis was extensive, covering conventional pollutants as well as trace metals analysis, specific organic analyses, and vaporous metals and organics using EPA's Level 1 environmental assessment procedure. Major findings of this study plus brief descriptions of the sampling and analysis procedures are summarized next. They are presented in the order of the streams listed above and are preceded by a summary of the incinerator operating parameters.

OPERATING PARAMETERS

During the 3 days of field tests, the Braintree incinerator was run at its design operating rate of 4.5 Mg/hr (about 5 tons/hr). Heat input rates to the boiler increased from 40 x 10^6 kJ/hr on the first day to 49 x 10^6 kJ/hr on the final day.

REFUSE FEED

Grab samples of the input refuse were taken each day for characterization of its components. The samples were hand sorted to remove glass, metal, and inerts from the combustible fraction, which later underwent laboratory analysis. The refuse had an average heat of combustion of 16,780 kJ/kg (7,214 Btu/lb). Corrections for the moisture content and percentage of glass, metal, and inerts showed that the "as received" solid waste had a heating value of 10,200 kJ/kg. The combustible fraction of the refuse contained 0.33% sulfur and 4.6% ash, based on results of the proximate/ultimate analysis.

BOTTOM ASH

Daily samples of the incinerator bottom ash were collected and analyzed for elemental compositions. Quantities of bottom ash generated by the combustion of refuse amounted to about 25%, by weight, of the input refuse. Spark Source Mass Spectrometry (SSMS) analysis showed an increase in the concentration of nearly every element in the bottom ash relative to the refuse feed. Even some of the more volatile elements, which would be expected to vaporize and be carried off with the flue gases (e.g., As, Sb, Pb), were found in greater concentrations in the bottom ash. There was a 10-fold increase in Pb, for example, after accounting for the mass ratio of bottom ash to input refuse. However, it should be noted that the hand sorting technique used to separate the combustible materials from the raw refuse could have allowed lead-containing metals to be incompletely separated from the paper and plastics.

QUENCH WATER

Since the bottom ash quench trough water continuously overflowed to a sewer system, grab samples were taken each day and analyzed for pH, total suspended solids (TSS), total dissolved solids (TDS), oil and grease, biological oxygen demand (BOD), chemical oxygen demand (COD), and phenol. The effluent discharge rate was approximately 227 liters/min (60 gpm). Samples of the inlet water were also taken to provide baseline comparison. In general, the water quality analysis results revealed moderately low concentrations, except for TDS which averaged 710 mg/liter at the outlet. Levels of phenol were all less than 0.1 mg/liter.

ESP INLET

Incinerator air emissions were sampled upstream of the precipitator to evaluate uncontrolled pollutants. The uncontrolled particulate emissions averaged 0.82 g/dscm (0.36 gr/dscf), or 0.60 g/MJ heat input (1.4 lb/10^6 Btu). In terms of an uncontrolled emission factor, about 11.3 lb of particulate were discharged for every ton of refuse charged to the incinerator.

Particle sizing data taken at the inlet proved to be erratic and no conclusions could be drawn regarding size distribution. It appears that, because of the large, flake-like nature of some of the refuse combustion particulate and the highly variable particle density, normal aerodynamic sizing by the Brink impactor, and particularly the precyclone, was impaired.

Analysis of the particulate catch for metals by atomic absorption (AA) showed relatively high levels of Pb in the uncontrolled particulate. Pb concentrations averaged 11.9 mg/dscm. Concentrations of Hg and As were low, (10 and 50 µg/dscm, respectively), while levels of Sb, Cd, Cu, and Fe were in the range of 100 to 1,000 µg/dscm.

In addition to these values, elemental analysis of the particulate samples by SSMS indicated average concentrations of Bi, Sn, Br, Zn, Ca, Ti, K, P, Si, Al, Na, and Mg which were greater than 1,000 µg/g (about 500 µg/dscm). The data also showed levels of Cl, F, and Br in this same range.

In situ particle resistivity tests were planned but could not be done because flue gas temperatures (up to 274°C) exceeded the maximum operating temperature of the resistivity probe of 205°C.

ESP ASH

Grab samples of the fly ash collected in the ESP hoppers were taken during each test period and analyzed for anions, polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbon (PAH) compounds, and elemental composition.

Concentrations of chlorides and sulfates averaged 41 and 10.4 mg/g, respectively. Levels of cyanides and nitrates were below the limit of detection, while F^- and Br^- concentrations were about 0.5 mg/g.

No PCBs were detected in the ESP ash. Concentrations were all below the detection limit of 0.4 ng/g. Four PAH compounds were identified in the ash samples, but their levels were below the range of reliable quantitative analysis (0.3 to 0.7 µg/g).

Several elements in the SSMS elemental composition data had concentrations in excess of 1%. These included Ca, K, Cl, P, Si, Al, Mg, and Na. The

concentrations of many elements increased in the collected fly ash relative to the uncontrolled particulate. This would seem to indicate that these elements were predominantly associated with larger sized particles. Conversely, there were also elements whose concentrations showed a definite decrease in the collected ash, namely Bi, Sb, Sn, Cd, Ag, Br, Se, As, Ga, Cu, and F. It is likely that these elements may be associated with smaller particles.

STACK EMISSIONS

Sampling and analysis of the incinerator stack emissions received major emphasis for the Braintree test program.

Gaseous analysis of the stack effluent showed the following concentrations:

Constituent	Average concentration	Range
NO_x	54 ppm	30-76
SO_2	48 ppm	5-151
CO	475 ppm	211-747
Total hydrocarbons	11.3 ppm	2.5-22.7
O_2	16.1%	13.9-18.1
CO_2	4.2%	3.6-5.0

Filterable particulate emissions, measured by EPA Method 5, averaged 0.55 g/dscm corrected to 12% CO_2, which exceeded the applicable state and federal emission regulations of 0.23 and 0.18 g/dscm, respectively (0.10 and 0.08 gr/scf). The total uncorrected concentration was 0.22 g/dscm (0.094 gr/scf), of which 11% was condensible particulate. The high particulate loadings can be traced to an apparent low collection efficiency of the ESP. ESP efficiency during MRI testing was determined to be only 74%, while its design efficiency was reported to be 93%. Monitoring of the ESP during sampling did not indicate any abnormalities in its operation. However, from subsequent discussions with plant personnel, it appears that the high particulate levels were most likely the result of mechanical problems in the operation of the incinerator and its related systems. These were not discovered until several months after the MRI tests were conducted (see Section 4). A new series of compliance tests have been conducted by others since the MRI tests and the emissions levels were found to be within the compliance regulations.

Andersen impactor particle size analysis showed an average particle size of about 3 μm at the ESP outlet. Approximately 22% of the particles were smaller than 0.6 μm and about 23% were 10 μm or larger, indicating a fairly uniform distribution of particle sizes in the stack emissions.

Characterization of the collected particulate included analyses for trace metals and elemental composition by SSMS. Trace metal concentrations in the outlet particulate showed basically the same relative distribution as was seen in the inlet particulate but at generally reduced levels. Pb, at 5,400 μg/dscm, had the highest concentration while As and Hg had the lowest (16 and 14 μg/dscm, respectively). In terms of ppm (μg/g), the concentrations of Pb, As, and Hg were 47,600, 145, and 124, respectively.

The concentration of mercury in the particulate at the outlet was higher than the concentrations prior to the ESP. At the outlet, mercury concentration averaged 0.014 mg/dscm.

PCB and PAH analysis of the outlet particulate was planned, but due to insufficient quantities of the particulate catch, the analysis could not be carried out. However, assays for PCB and PAH compounds were performed on the fly ash captured by the ESP as discussed in the earlier section (i.e., ESP ash). SSMS results showed that the concentrations of most elements decreased slightly or remained essentially the same in the stack emissions when compared to the uncontrolled emissions. Some elements increased in concentration and the most prevalent elements were Pb, Zn, Si, and Al.

A special sampling train was used to collect carbonyls and results showed very low concentrations, averaging 1.3 ppm.

Another absorbent train was used to sample for vaporous mercury and selected anions (Cl^-, F^-, Br^-, and CN^-). Vaporous Hg concentrations varied widely from 30 to 1,800 $\mu g/m^3$. The average was 560 $\mu g/m^3$. The wide variation in Hg levels could have been the result of fluctuations in mercury-bearing materials in the refuse. Results of the anion analysis showed all concentrations at or near the limits of detection. The highest chloride concentration was 190 $\mu g/m^3$ (130 ppm).

Stack emissions sampling was also conducted using SASS equipment as specified in EPA's Level 1 procedures. This train is specially designed to collect organic and trace metals components of the flue gas stream as well as particulate in three size fractions. The SASS cyclone catches indicated that 43% of the particulate was 1 μm or smaller in size.

PCB analysis revealed observable levels only in the XAD-2 resin of the SASS train. About 100 μg of PCB (reported as DCB) were detected, which corresponds to a concentration of 4 $\mu g/m^3$. The PCB concentration in the particulate was below the detectability of the GC/MS analysis technique used.

Four PAH compounds were quantitatively identified in the XAD-2 resin and aqueous condensate. All levels, however, were quite low. Highest observed concentration was 4 $\mu g/m^3$.

Level 1 analysis for the vaporous metals As, Sb, and Hg showed the highest concentrations in the particulate sample fraction, indicating possible adsorption of these metals on the particulate. Sb showed the greatest increase in concentration in the finer particle sizes.

Organic analysis of the SASS train components was carried out in accordance with Level 1 protocol. These data were interpreted using EPA's Source Analysis Model (SAM-1A) which is discussed below.

SAM-1A

Because of the difficulty involved in interpreting much of the data collected in this program, especially the Level 1 analysis results, the environmental assessment work was extended to include application of the methodology known as SAM-1A, recently developed by EPA.

This methodology was applied to the Braintree data for the four effluent streams, bottom ash, quench water, ESP ash, and stack emissions. Results showed that the stack emissions had the highest degree of hazard (H value), but this was primarily due to groups of organic compounds which could not be individually identified and therefore were assigned a conservatively low Minimum Acute Toxicity Effluent (MATE) value in accordance with the SAM-1A methodology. The bottom ash stream had the highest Toxic Unit Discharge Rate (TUDR), due to several metals present in high concentrations. This finding would seem to indicate that the bottom ash stream should receive the highest priority for control or removal of specific metallic constituents. However, considering the physical nature of the bottom ash and the methods for its disposal, further work should be done to better assess its environmental hazard potential.

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METRIC CONVERSION FACTORS USED IN THIS REPORT

To convert from English	To Metric	Multiply by
Btu	kJ	1.055
Btu/lb	kJ/kg	2.326
ft	m	3.048 E-01
ft^2	m^2	9.290 E-02
ft^3/min	m^3/min	2.832 E-02
gal/min	liter/min	3.785
gr/scf	g/dscm	2.288
lb	kg	4.536 E-01
lb/ft^3	kg/m^3	1.603 E-01
lb/10^6 Btu	kg/MJ	4.300 E-01
psi	kPa	6.895
ton	Mg	9.072 E-01
yd^3	m^3	7.646 E-01

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The Midwest Research Institute project manager is Mr. M. P. Schrag and the project leader is Dr. K. P. Ananth. The report was authored by Mr. Mark Golembiewski with assistance from Dr. Glenn Trischan and Mr. Emile Baladi. Recognition is also given to the members of Midwest Research Institute's Field Programs Section and Analytical Chemistry Section for their contribution to the sampling and analysis portions of this program.

SECTION 1

INTRODUCTION

MRI is conducting a series of environmental assessments of generic waste-to-energy processes for the EPA. The Braintree Municipal Incinerator (waterwall type) in Braintree, Massachusetts, is one of the major waste-to-energy systems investigated within this program.

The Braintree facility consists of dual, waterwall furnaces, completed in 1971 as a replacement for the town's sanitary landfill. Each mass burn unit was designed to incinerate 120 tons of unprocessed refuse per 24-hr period, although higher tonnages have been achieved while maintaining proper incinerator operating conditions. Mixed municipal refuse is delivered by packer truck to the plant from the Town of Braintree and several surrounding communities.

Air pollution controls at the incinerator consist of an ESP (manufactured by Wheelabrator-Frye) for each boiler unit. Design efficiency of each ESP is claimed to be 93% for cleaning 906 acmm at 316°C. The two collection devices exhaust to a common stack.

The following sections of this test report contain a more detailed description of the test facility, an overview of the sampling and analytical strategies used, and a discussion of the results of the test program. An assessment of the results using EPA's SAM-1A and a presentation of conclusions and recommendations based on the findings of this analysis are also included.

When drawing conclusions from the data presented in this report, the reader should be cautioned that air emissions during the MRI tests may not have been representative of <u>optimum</u> operating conditions, due to potential mechanical problems in the system which were identified subsequent to the MRI tests (see Sections 4 and 6). However, the tests do reflect operating conditions as they existed during the time of testing.

SECTION 2

DESCRIPTION OF BRAINTREE INCINERATOR FACILITY

The Braintree plant, completed in 1971, consists of twin waterwall incinerators, each with a design capacity of 109 Mg of refuse per 24-hr period. Each unit is equipped with an ESP for emission control and both ESPs exhaust to a common stack. Figures 1 and 2 show a cross-section of the incinerator system and a top view of the control equipment configuration, respectively.

Municipal refuse is brought to the Braintree plant by truck and dumped into a 1,025 m^3 receiving pit. Care is taken to exclude bulky items such as tires, furniture, etc., which might jam the incinerator feed hoppers. An overhead crane equipped with a grapple bucket is used to load the charging hoppers (one per furnace) with material from the pit. Each grapple bucket load is approximately 1,087 kg.

Refuse charged to the furnace falls first onto an inclined grate where initial drying of the refuse occurs. The burn grate is a horizontal, traveling grate (Riley Stoker Company) designed for a heat release rate of 3,240 MJ/m^2/hr. Grate speed is about 9.1 m/hr. Underfire air is supplied to the refuse bed by a forced air fan, but no overfire air is normally used. Residual ash and noncombustible material are discharged at the end of the grate into a water-filled quench trough. The quenched material is continually removed by a drag chain conveyor and deposited in a dump truck which transports the ash to a nearby landfill. Quench water is disposed of via the city sanitary sewer system.

The boiler units are of the single pass design and were supplied by Riley Stoker Company. Each furnace contains 83 m^2 of waterwall heating surface prior to the boiler tube section. This is then followed by an economizer section. Additional boiler specifications are listed below:

Manufacturer: Riley Stoker Company

Year built: 1971

Model: Type RX

Rated capacity: 13,600 kg/hr (30,000 lb/hr) of steam

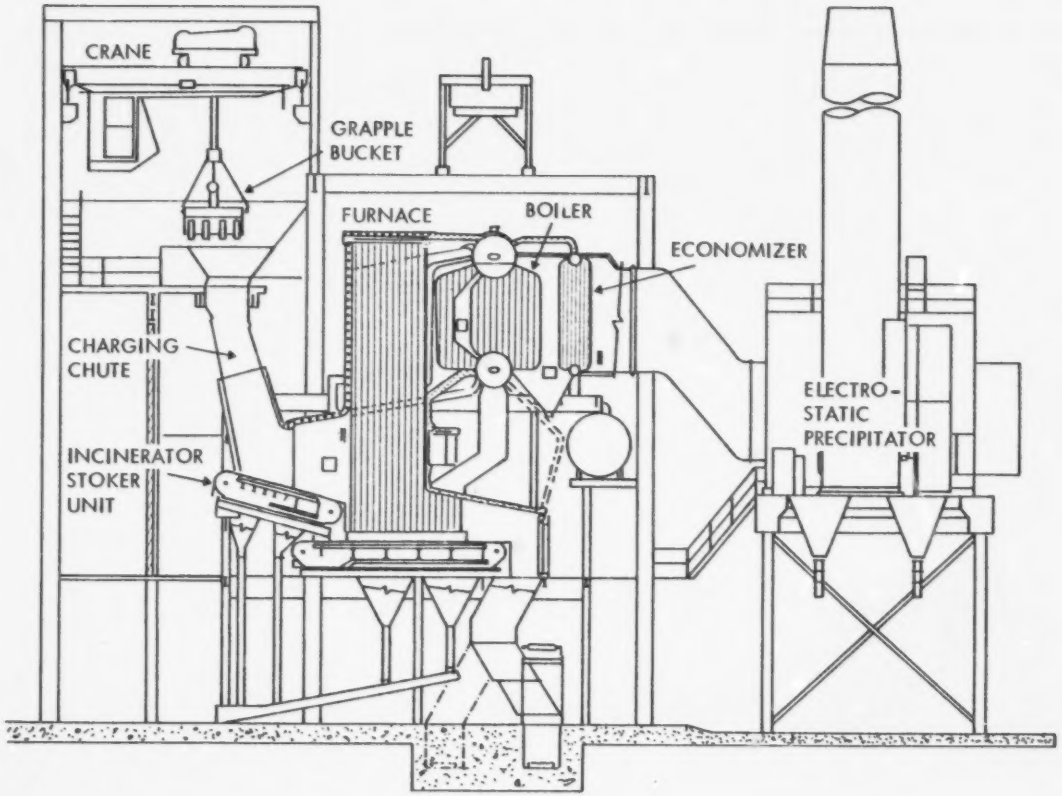

Figure 1. Braintree municipal thermal waste conversion station, Braintree, Massachusetts.

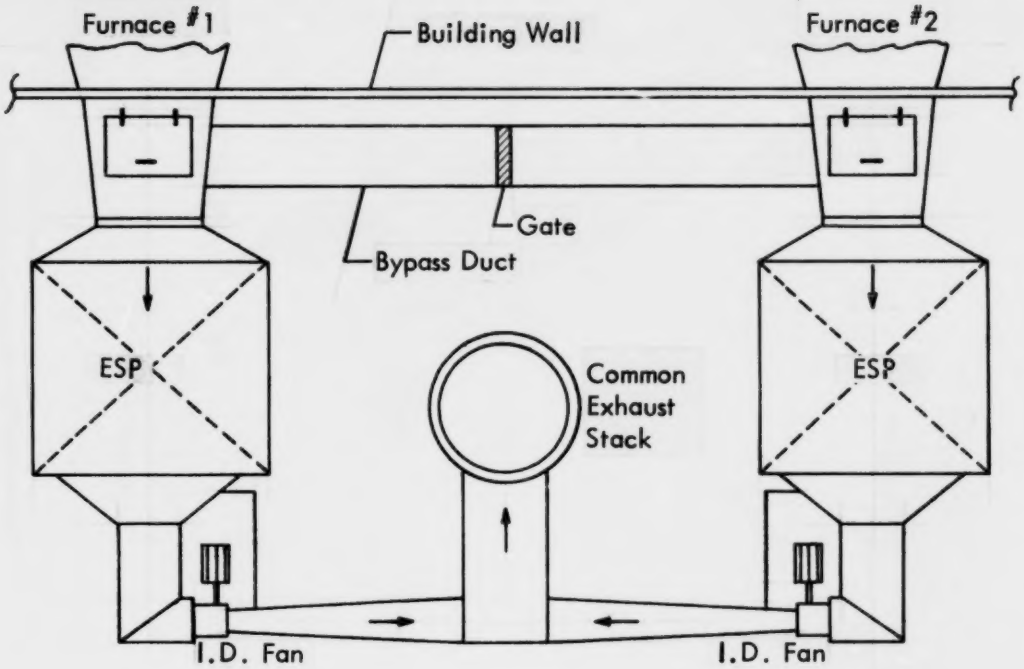

Figure 2. Plan view of ESP and breeching arrangement.

Design pressure: 1,724 kPa (250 psig)

Design temperature: 208°C (saturated)

Furnace volume: 78.7 m^3

Furnace area: 102 m^2

Waterwall heating surface area: 83 m^2

Total heating surface area: 307 m^2

A portion of the steam produced (varying from 20 to 35% based on demand) is piped to nearby industrial users. The remainder is dissipated via two rooftop condensers since there is no other local market for the steam generated.

Temperatures in the furnace combustion zone are of the order of 1320°C, with excess air levels sometimes exceeding 400%. Flue gas temperatures at the exit of the economizer section normally range from 200 to 320°C. After leaving the economizer, exhaust gases from the incinerators are directed into individual ESPs. A bypass duct connects the inlet sections to the ESPs (see Figure 2), allowing the exhaust gases from one boiler to be diverted through both precipitators in parallel or to the opposite ESP. Specifications for the precipitators are given below:

Manufacturer: Wheelabrator-Frye

Number of passages: 12

Number of fields: Single field

Plate-to-plate spacing: 25.4 cm

Plate height: 4.6 m

Plate collecting area: 440 m^2

Specific collection area (SCA): 413 m^2/1,000 acmm (126 ft^2/1,000 acfm)

Gas velocity: 1.04 m/sec

Design collection efficiency: 93%

After passing through the precipitator, the boiler flue gases enter the ID fan and are discharged through a metal stack common to both precipitator units. Exhaust gas flow rates from each of the ESPs are in the range of 425 to 710 scmm (15,000 to 25,000 scfm). Particulate matter collected by the precipitators is sluiced with water into the incinerator bottom ash quench trough.

SECTION 3

SAMPLING AND ANALYSIS METHODOLOGY

The environmental assessment program carried out at the Braintree incinerator consisted primarily of the determination of flue gas constituents. The sampling efforts also included measurements of the refuse feed and the solid and liquid effluent streams. The major tasks of the test program were as follows:

1. Quantification and characterization of refuse fed into the incinerator.

2. Quantification and characterization of bottom ash discharged from the incinerator.

3. Monitoring and adjustment of the ESP operating parameters (by Southern Research Institute (SRI)).

4. Determination of particulate loading in the flue gases entering the ESP.

5. Determination of particulate loading in the gases leaving the ESP plus analysis of the particulate and gaseous components.

All tests were conducted while the incinerator was operated at its design refuse feed rate of 4.5 Mg/hr (5 tons/hr). Actual feed rates during the 3 days of testing ranged from 4.1 to 4.7 Mg/hr. It should be noted, however, that "normal" furnace operating conditions have been as high as 7.3 Mg/hr (8 tons/hr). Testing was carried out with Boiler No. 1 in operation and the flue gases diverted through the bypass arrangement to the No. 2 ESP (see Figure 2). This was done to provide more suitable sampling conditions (smoother velocity profile) at the inlet to the collector. The sequence of the sampling program is shown in Table 1.

TABLE 1. BRAINTREE TEST SCHEDULE

Test No.	Date	Test period	Comments
1	1/17/78	9:00-17:15	
2	1/18/78	9:30-18:45	Included SASS run
3	1/19/78	9:15-16:00	

Sampling and analysis of the air, water, and solid waste effluent streams were undertaken as shown in Figure 3. A summary of the analyses performed on each sample, and the methodology employed, is shown in Table 2. Detailed descriptions of the analytical procedures are contained in Appendix A. The sampling and analysis schemes for each input/effluent stream are discussed next in the general order of flow through the process.

REFUSE FEED TO BOILER

Once each test day, a crane bucket load of raw refuse weighing approximately 1,090 kg (2,400 lb) was deposited alongside the holding pit. A 90 kg (200 lb) sample was extracted and manually sorted into three categories: metals, glass, and "other" (primarily combustibles). Each of the three material fractions were then weighed and the data recorded. The metals and glass portions were returned to the refuse holding pit, while a 1 ft^3 sample of the combustibles fraction was placed in a plastic bag and returned to MRI for further analysis. A total of three samples were obtained by this method.

A portion of each combustible fraction was used to determine the moisture content, after which the sample was ground and submitted for proximate and ultimate analyses and higher heating value determination. Another portion of the material was analyzed by SSMS for quantification of elemental concentrations.

The quantity of refuse fed to the incinerator during each test period was determined by recording the number of grapple bucket loads charged to the incinerator, assuming an average bucket load weight of 1,090 kg (2,400 lb). This weight-per-bucket-load had been established over a period of time by Braintree operating personnel.

BOTTOM ASH

Sampling and analysis of the incinerator bottom ash involved protocols similar to those adopted for the raw refuse. A 1 ft^3 sample was obtained from the collection truck during each hour of the test period. The samples were composited at the end of each day and manually segregated into three categories: metals, glass and "other." After weighing each of the three fractions, a 1 ft^3 sample of the "other" portion was placed in a plastic bag and transported to MRI for analysis.

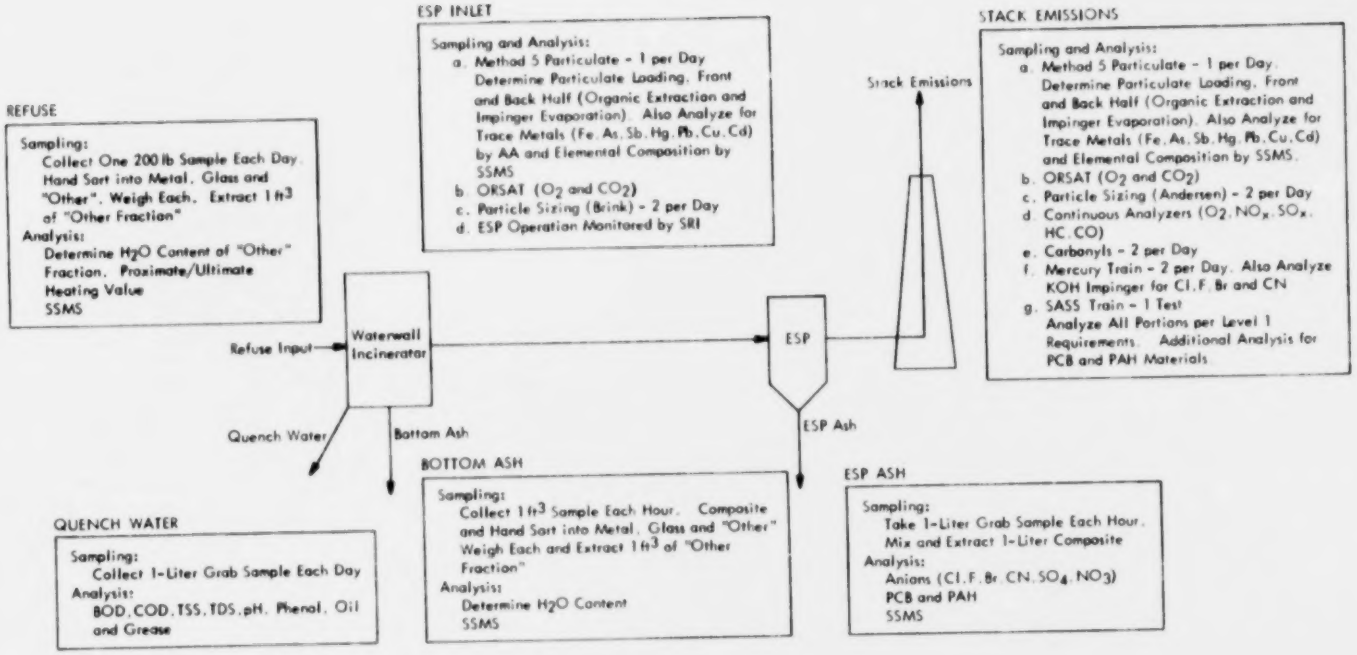

Figure 3. Sampling and analysis matrix for the Braintree municipal incinerator.

TABLE 2. SUMMARY OF ANALYSIS METHODS

Sample	Parameter	Analytical method
Refuse	Proximate	
	Moisture	Modified ASTM Method D-3172-73
	Ash	
	Volatile matter	
	Fixed carbon	
	Sulfur	
	Heat of combustion	
	Ultimate	
	Hydrogen	Modified ASTM Method D-3176-74
	Carbon	
	Nitrogen	
	Oxygen	
	Elemental composition	Spark source mass spectrometry
Bottom ash	Elemental composition	Spark source mass spectrometry
Quench water	Water quality	
	pH	EPA Manual of Methods for Chemical Analysis of Water and Wastes (1974)
	Oil and grease	
	TSS	
	BOD	
	COD	
ESP inlet	Particulate mass	EPA Method 5 (California modification)
	Moisture content	EPA Method 5
	$O_2 + CO_2$	Orsat/Fyrite
	Particle sizing	Brink impactor (gravimetric)
	Elemental composition	Spark source mass spectrometry
	Trace metals	Atomic absorption spectroscopy

(continued)

TABLE 2. (continued)

Sample	Parameter	Analytical method
ESP ash	Anions	
	Chloride	Oxygen combustion, ion selective electrodes
	Fluoride	Oxygen combustion, ion selective electrodes
	Bromide	Oxygen combustion, ion selective electrodes
	Cyanide	Water extractable, ion selective electrodes
	Sulfate	Water extractable, barium-thorin titration
	Nitrate	Water extractable, colorimetric with phenol disulfonic acid
	Polynuclear aromatic hydrocarbons	Gas chromatography/mass spectrometry
	Polychlorinated biphenyls	Gas chromatography/mass spectrometry and derivatization gas chromatograph with electron capture
	Elemental composition	Spark source mass spectrometry
ESP outlet	Particulate mass	EPA Method 5 (California modification)
	Water	EPA Method 5
	Mercury	Method developed by Statnick (see Appendix A)
	$O_2 + CO_2$	Orsat, with O_2 also determined by continuous analysis
	Particle sizing	Andersen impactor (gravimetric)
	Opacity	EPA Method 9
	Chloride	Collected in 5% KOH impinger in mercury train. Analyzed using ion selective electrodes
	Fluoride	Collected in 5% KOH impinger in mercury train. Analyzed using ion selective electrodes
	Bromide	Collected in 5% KOH impinger in mercury train. Analyzed using ion selective electrodes
	Cyanide	

(continued)

TABLE 2. (continued)

Sample	Parameter	Analytical method
ESP outlet (continued)	Gases	
	SO_2	EPA Method 6
	NO_x	EPA Method 7 and continuous monitor
	O_2	Orsat
	CO_2	Orsat
	CO, O_2, HC	Continuous monitor
	Carbonyl compounds	Titration
	Level 1	
	Particulate sizing	SASS - Level 1
	Organic	SASS - Level 1 - gravimetric, gas chromatography, infrared, liquid chromatography, mass spectrometry
	Inorganic	SASS - Level 1 - spark source mass spectrometry, atomic absorption
	Elemental composition	Spark source mass spectrometry

The moisture contents of the three samples were determined, after which the samples were ground and analyzed for elemental content by SSMS.

The discharge rate of bottom ash from the incinerator was determined from the weight of each truckload of ash removed. The trucks were weighed on the plant's weigh scale near the tipping floor and the tare weight of the vehicle was subtracted to arrive at the net ash weights.

QUENCH WATER

Water from the quench trough continually overflows to the municipal sewer system and is therefore an effluent stream. A 1 liter grab sample of the outfall was collected each day and analyzed for BOD, COD, TSS, pH, phenols, and oil and grease. Samples of the quench trough input water (city water) were also taken to provide baseline data. The approximate effluent flow rate was determined by computing the time required to fill a 19-liter (5-gal.) container.

ESP INLET

Prior to each test, SRI personnel checked and adjusted the ESP for optimum collection efficiency. In addition, SRI monitored and recorded ESP operating parameters for performance evaluation purposes. Thereafter the sampling and analysis at the ESP inlet consisted of the following:

Method 5 particulate. One Method 5 particulate test was carried out each day at the ESP inlet. Particulate concentrations were determined from the front half particulate catch and from the back half of the train (impinger water), including CCl_4 extraction of the impinger water. Particulate collected on the filter was analyzed for elemental composition by SSMS, and by AA for seven metals (Fe, As, Sb, Hg, Pb, Cu, and Cd).

Orsat analyses were performed three times per day to determine the molecular weight of the flue gas (percent O_2 and CO_2) and percent excess air.

Particle size distribution. A Brink impactor was used to determine particle size distribution at the ESP inlet. Two impactor tests were performed on each test day. The weight of material collected on each stage of the Brink was determined at the test site and the material saved for possible future analysis.

In situ resistivity. SRI was to determine in situ resistivity. However, flue gas temperatures exceeded instrument capabilities (~ 200°C), and the in situ tests could not be performed.

ESP ASH

Although the ESP ash is ultimately sluiced with water into the bottom ash quench trough, samples of the dry ash were taken as it was discharged from the

ESP ash hopper. One liter grab samples were taken each hour during the test periods. The grab samples were composited at the end of each test day and a 1 liter composite was retained for analysis. The laboratory analyses included determinations of elements by SSMS, anions (Cl^-, F^-, Br^-, $SO_4^=$, NO_3^-, and CN^-), and PCB and PAH compounds.

ESP OUTLET

Emissions from the ESP were sampled and analyzed for several constituents, both in particulate and vapor form, as discussed below.

Method 5 particulate. One particulate test was carried out each day at the outlet from the ESP, using the standard Method 5 sampling train. This was done simultaneously with the inlet sampling. Particulate concentrations were determined similarly to the inlet and analyzed by SSMS and by AA for seven metals.

Orsat analyses. Three Orsat analyses were performed during each test for O_2 and CO_2 to determine molecular weight of the flue gas and percent excess air. The data were also used for comparison with similar analyses at the ESP inlet.

Particle size distribution. An Andersen cascade impactor was used to determine particle size distribution of the particulate in the flue gas leaving the ESP. Two Andersen tests were performed on each test day. The material collected on each stage of the Andersen was saved for possible future analysis.

Opacity. Visual observations of the stack plume opacity using EPA Method 9 were planned. However, readings could not be obtained because of snow and rain conditions.

Continuous analyzers for O_2, NO_x, SO_2, HC, and CO. MRI set up these five continuous analyzers in a field trailer, using a heated sample line from the ESP outlet duct to the trailer. Values from each instrument were recorded at 15-min intervals on log sheets, even though permanent records are provided by the associated strip chart recorders.

Carbonyls. An impinger bubbler train was used to obtain two samples of the outlet flue gas each day. Analysis of the impinger solutions for carbonyl materials were conducted on site, as prescribed in the Bay Area regulations (Chapter 5)[1] as well as the Los Angeles APCD Source Testing Manual.[2]

Hg vapor analysis (including Cl, F, Br, and CN anions). An impinger sampling train as described by Statnick[3] (with two slight modifications by MRI) was used for vaporous mercury and anion sampling. A KOH solution was substituted for Na_2CO_3 in the first impinger for removal of SO_2 and other interferences. The KOH solution was analyzed for Cl, Br, F, and CN anions, as well as for Hg. The second and third impingers (midget) contained acidic $KMnO_4$ for

absorption of vaporous mercury. The fourth impinger was dry and the fifth contained silica gel. Two sampling runs were made each day using this special train.

SASS train. The SASS is a sampling train prescribed by EPA for environmental assessment work. It is somewhat similar to, but more complex than, the EPA Method 5 train. Basic components of the SASS train are shown in Figure 4. It is different from the Method 5 train (see Figure B-8, Appendix B) in that the filter is preceded by three cyclones and followed by an XAD-2 resin cartridge for collection of organic materials. The impingers which follow the XAD-2 module contain a solution for collection of vaporous metals (i.e., As, Hg, Sb).

Analysis of the SASS train components, as prescribed by EPA's Level 1 environmental assessment procedure, is quite complex. A presentation of the required analysis matrix is shown in Table 3. This matrix is in accordance with a Level 1 assessment, with the deletion of particle morphology and bioassay. However, for the purposes of this test program, MRI has added analyses for PCB and PAH compounds as indicated in Table 3.

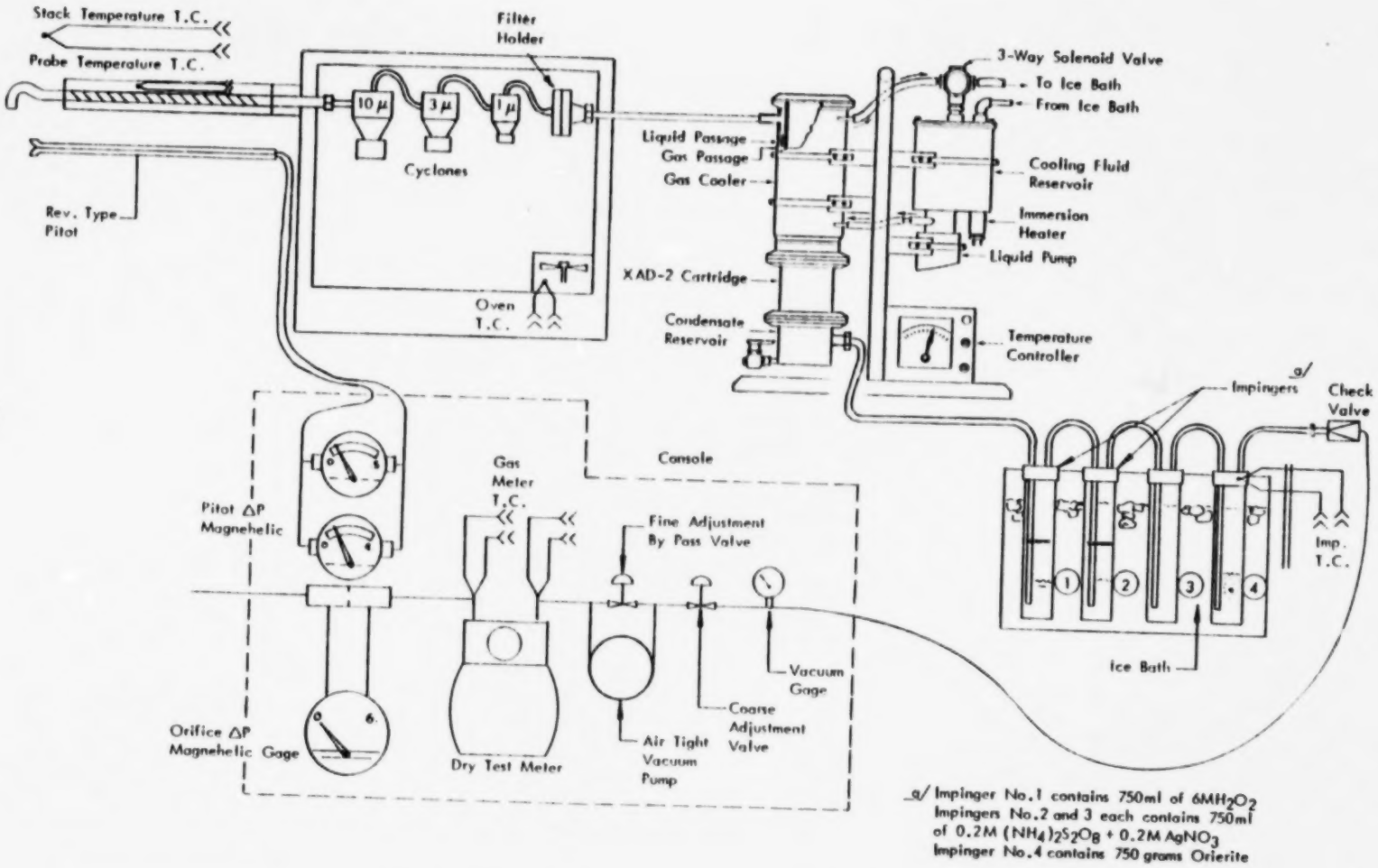

Figure 4. Schematic of the source assessment sampling system (SASS train).

TABLE 3. ANALYSIS MATRIX FOR SASS TRAIN COMPONENTS

	Particulate							
	Probe and cyclone rinse	10 μm	3 μm	1 μm	Filter	XAD-2 resin	Aqueous condensate	Impinger solutions
EPA LEVEL 1 PROTOCOL								
SSMS	X	X	X	X	X	X	X	X[a/]
As, Sb, and Hg by atomic absorption		X	X	X	X	X	X	X
CH_2Cl_2 extraction		Combined		Combined				
Gravimetric		X		X		X	X	
IR analysis		X		X		X	X	
LRMS analysis		X		X		X	X	
LC (7 fractions)[b/]		X		X		X	X	
ADDITIONAL ANALYSES SELECTED BY MRI								
PCB material		X		X		X	X	
PAH compounds		X		X		X	X	
Corrosion test							X	X

a/ Hydrogen peroxide impinger only.

b/ Dry and weigh each fraction. Analyze by IR and LRMS.

SECTION 4

PRESENTATION AND DISCUSSION OF TEST RESULTS

Test data, analytical results, and interpretation of the results are presented in this section. Because of the multiplicity and complexity of the analytical work, subsections delineating each of the input/output streams are separately discussed below. Boiler operating parameters and input/output flow rates determined during testing are discussed first to provide a basis for the subsequent analytical results and interpretations.

INCINERATOR OPERATING CONDITIONS AND MATERIAL FLOW RATES

Material flow rates determined during the three tests on the Braintree incinerator included refuse input, bottom ash, ESP ash, and boiler flue gas. Input/output measurement results are shown in Table 4. During the test program, the refuse feed rate was maintained very near the design rating for the boiler, i.e., 4.5 Mg/hr (5.0 tons/hr). The average feed rate for the 3 days of sampling equaled the design rate. Bottom ash was generated at an average rate of 1.45 Mg/hr (1.6 tons/hr), which amounts to about 36% of the refuse input rate on a wet weight basis (or 0.36 Mg of bottom ash per megagram of refuse feed). After correcting for the moisture absorbed by the bottom ash in the quench trough, this value drops to 1.15 Mg/hr or 25% of the refuse input rate. The bottom ash was also observed to contain some combustible material as a result of incomplete combustion. Fly ash collected by the ESP averaged 0.019 Mg/hr, over the 3 day test period.

A similar comparison can be made, although not as direct, between refuse input and the volume of flue gases produced. In this study, approximately 7,890 Nm^3 of gaseous effluents (average) resulted from the combustion of each ton of refuse. It must be realized, however, that combustion air conditions are controlled by the boiler operator and are dependent on manual adjustments to the firing conditions. These changes are dictated by fluctuations in refuse composition, ambient conditions, and normal operating practices.

Furnace operating conditions recorded during the tests are presented in Table 5. For the most part, the boiler parameters remained relatively constant during the sampling program, except for the steam header pressure which steadily declined from an average of 172 psig on Day 1 to 118 psig on Day 3.

TABLE 4. INPUT/OUTPUTS MEASURED DURING BRAINTREE TESTS

Test no.	Date and test period	Refuse feed (Mg/hr)	Bottom ash removed[a]	ESP ash removed (Mg/hr)	Flue gas from boiler (Nm^3/min)
1	1/17/78 9:00-17:15	4.7	2.08	0.018	742
2	1/18/78 9:30-18:45	4.6	1.38	0.017	577
3	1/19/78 9:15-16:00	4.1	1.38	0.023	456
Average		4.5	1.61	0.019	592
Average flow in Mg per Mg of refuse		1.0	0.36	0.0042	

a/ Bottom ash quantity measured after removal from water quench trough. (Mg/hr)

TABLE 5. FURNACE OPERATING CONDITIONS (AVERAGES)

Parameter	Test No. 1	Test No. 2	Test No. 3
Date	1/17/78	1/18/78	1/19/78
Test period	9:00-17:15	9:30-18:45	9:15-16:00
Refuse feed rate			
(Mg/hr)	4.7	4.6	4.1
(10^6 kJ/hr)[a]	40.4	46.0	49.0
Grate speeds (dial settings)			
Feed stoker	15	15	15
Burn stoker	30	30	30
Furnace draft (in. H_2O)	0.02	0.02	0.02
Furnace temperature (°F)			
Firebox	1114	1160	1134
Outlet gas	483	500	506
Steam flow (lb/hr)[b]	21,200	27,100	28,400
Steam header pressure (psig)	172	142	118

a/ Based on average gross calorific value determined for refuse feed each day ("as received" basis).

b/ Uncorrected chart readings.

REFUSE FEED

Results of the refuse hand sorting into metal, glass, and "other" fractions is shown in the tabulation below.

Components of Refuse at Braintree Incinerator

Run No.	% Metal	% Glass	% "Other"
1	7.3	11.1	81.6
2	7.4	12.5	80.1
3	7.0	13.9	79.1
Average	7.2	12.5	80.3

These data indicate that about 80% of the refuse combusted in the Braintree incinerator during the test period was essentially combustible material. Laboratory analyses performed on the combustible fractions of the refuse feed samples (after removal of metal and glass components) consisted of:

- Free moisture;
- Proximate analysis;
- Ultimate analysis;
- Heat of combustion; and
- Elemental analysis (by SSMS).

Tables 6 and 7 present results of the above determinations.

Most composition characteristics of the refuse remained fairly constant over the course of the 3 day sampling program. One parameter which did vary quite widely was the "free" moisture content. As seen in Table 6, this value declined from a high of 32% on the first day of testing to a low of 7% on the final day. This trend is difficult to understand, especially when considering that it rained during most of the 2nd day of testing and was generally damp during the entire test period. The decline in moisture content, however, does correspond well with the progressive increase in the "as fired" heating value shown in line 5 of Table 6.

No unusual characteristics were observed in the elemental analysis of the refuse fuel. Those elements which were found to be predominant were the common earth elements, i.e., Fe, Ti, Ca, K, S, P, Si, Al, Mg, and Na.

TABLE 6. REFUSE ANALYSIS[a/]

Test No. Date	1 1/17/78	2 1/18/78	3 1/19/78	Average
1. Free moisture (%)[b/]	32.0	17.0	7.0	18.7
2. Proximate analysis (%)[c/]				
H_2O	7.43	7.51	7.26	7.40
Ash	2.35	3.93	6.57	4.28
Volatile matter	75.64	75.29	73.40	74.78
Fixed carbon	14.58	13.27	12.77	13.54
	100.00	100.00	100.00	100.00
3. Ultimate analysis (%)[d/]				
Ash	2.53	4.25	7.09	4.62
C	48.71	47.16	45.84	47.24
H	6.31	6.01	6.12	6.15
O	41.68	41.90	40.57	41.38
S	0.36	0.35	0.27	0.33
N	0.41	0.34	0.12	0.29
	100.00	100.01	100.01	100.01
4. Heating value (kJ/kg)[d/]	16,777	16,056	17,508	16,780
5. Heating value of "as fired" refuse (kJ/kg)	8,618	9,999	11,943	10,187

a/ Analysis performed on combustible component of refuse, i.e., metals and glass components removed.

b/ Free moisture is based on weight loss when samples were dried to a constant weight using an air stream 5°C above ambient temperature. Samples dried in this manner were then used for proximate and ultimate analyses.

c/ "As received" basis.

d/ Of combustible fraction on a dry basis.

TABLE 7. ELEMENTAL ANALYSIS OF REFUSE BY SSMS (μg/g)[a/]

Element	Run No. 1	Run No. 2	Run No. 3	Average	Element	Run No. 1	Run No. 2	Run No. 3	Average
Uranium					Rhodium				
Thorium					Ruthenium				
Bismuth	< 0.12	0.13	0.20	< 0.15	Molybdenum	0.35	1.1	1.0	0.82
Lead	7.0	15	14	12	Niobium	0.32	0.52	1.5	0.78
Thallium					Zirconium	0.70	4.8	3.0	2.8
Mercury					Yttrium	0.29	0.27	0.48	0.35
Gold					Strontium	6.5	5.9	8.7	7.0
Platinum					Rubidium	1.1	0.48	2.6	1.4
Iridium					Bromine	0.80	0.74	0.79	0.78
Osmium					Selenium	0.05		< 0.36	≤ 0.17
Rhenium	NR	NR	NR	NR	Arsenic		0.79	< 0.12	≤ 0.39
Tungsten					Germanium				
Tantalum					Gallium		0.16	0.34	< 0.20
Hafnium	< 0.19	< 0.17	< 0.18	< 0.18	Zinc	20	30	75	42
Lutecium					Copper	11	18	14	14
Ytterbium	< 0.13	< 0.12	< 0.13	< 0.13	Nickel	0.92	2.5	6.8	3.4
Thulium					Cobalt	0.21	0.82	0.88	0.64
Erbium	< 0.12	< 0.11	< 0.12	< 0.12	Iron	140	270	505	305
Holmium					Manganese	7.7	14	22	13
Dysprosium					Chromium	2.2	10	6.1	6.1
Terbium					Vanadium	8.0	34	51	31
Gadolinium					Titanium	350	640	~ 2,050	~ 1,000
Europium					Scandium		0.12	0.19	0.14
Samarium					Calcium	~ 1,100	~ 3,000	~ 3,800	~ 2,600
Neodymium			0.36	≤ 0.19	Potassium	~ 1,400	380	~ 740	~ 840
Praseodymium	0.13	0.23	0.22	0.19	Chlorine	20	15	13.7	16
Cerium	0.68	1.5	2.0	1.39	Sulfur	560	280	790	540
Lanthanum	0.26	0.50	1.3	0.69	Phosphorus	380	300	310	330
Barium	8.5	17	35	20	Silicon	~ 0.13%	~ 0.45%	~ 0.5%	~ 0.36%
Cesium					Aluminum	0.6%	< 0.5%	~ 0.7%	~ 0.60%
Iodine					Magnesium	200	360	670	410
Tellurium					Sodium	320	300	~ 2,050	890
Antimony	0.32	0.30	0.63	0.42	Fluorine	7.0	26	21	18
Tin	0.72	0.66	1.98	1.12	Oxygen	NR	NR	NR	NR
Indium	NR	NR	NR	NR	Nitrogen	NR	NR	NR	NR
Cadmium	0.11	0.67	< 0.16	≤ 0.31	Carbon	NR	NR	NR	NR
Silver	0.1	0.1	< 0.21	≤ 0.14	Boron	NR	NR	NR	NR
Palladium					Beryllium				
					Lithium	NR	5.1	3.7	4.4[b/]

a/ Blank spaces indicate values less than 0.1 μg/g.

b/ Based on two values.

NR = Not run.

Most of the analytical work in this study included additional work on quality assurance. That is, sample analyses were replicated to assess precision of the analytical results and reference materials and/or sample fortifications were used to assess accuracy of the results. Quality assurance data, for the analyses performed on the refuse samples, are contained in Appendix A. These data generally confirm the analytical results. Although an analysis of a Bureau of Mines refuse sample was included in this program, a specific assessment of analytical accuracy of the refuse feed could not be made since the elemental composition of the reference material is not certified. Since SSMS analysis for elemental composition is a semiquantitative technique and since the refuse feed is quite variable, it is not surprising that the analytical precision of some elements is not high.

BOTTOM ASH

Furnace bottom ash was sampled and analyzed to determine the moisture content and elemental composition of the residual and noncombustible material resulting from refuse combustion in the Braintree incinerator. Since the ash samples were collected after the material had been removed from the bottom ash quench trough (by drag chain conveyor), the percent moisture values allow calculation of the ash production on a dry basis (prior to quenching). The tabulation below shows the average bottom ash production rate.

Quantities of Bottom Ash Produced

Test Day	Refuse Feed Rate (Mg/hr)	Bottom Ash Rate - Wet (Mg/hr)	Percent Moisture	Bottom Ash Rate - Dry (Mg/hr)	Dry Bottom Ash Relative to Refuse
1	4.7	2.08	23	1.60	34%
2	4.6	1.38	33	0.92	20%
3	4.1	1.38	33	0.92	22%
Average	4.5	1.61	30	1.15	25%

After collecting the wet bottom ash samples, they were hand sorted to segregate the glass, metal, and "other" fractions. The resulting composition data are shown below.

Composition of Bottom Ash From Braintree Incinerator*

Run No.	% Metal	% Glass	% "Other"
1	17.3	36.4	46.3
2	8.1	21.6	70.3
3	11.5	23.5	65.0
Average	12.3	27.2	60.5

* Wet basis - samples taken from bottom ash truck after removal from quench trough.

Elemental composition analysis by SSMS was conducted on the furnace bottom ash to determine the concentration of elements, particularly trace metals, remaining in the residual material after mass burning. It serves also as a semiquantitative means of providing data for relating the more predominant elements in terms of a system mass balance. SSMS analysis was performed on the particulate portions of all the inlet and outlet material streams. Results of this analysis for the furnace bottom ash (with metal and glass removed) are presented in Table 8.

The more predominant trace metals in this effluent stream were Pb, Sr, Zn, Cu, Fe, Mn, Ti, Si, Al, and Mg. Even though some uncertainty is inherent in these results because of the semiquantitative nature of SSMS analysis, many of the elements are found to be concentrated in the bottom ash relative to the refuse feed stock. Most notable are the concentrations of Pb, Ba, Sb, Sn, Sr, Zn, Cu, Fe, Mn, S, P, Mg, and Na. It is difficult to understand the increased lead concentration in the bottom ash since Pb has a low melting point.

The refuse analysis was conducted on the "combustible" fraction of the total material sample (i.e., incoming waste minus metal and glass). The bottom ash analysis was also performed on that portion of the sample remaining after removal of metal and glass. The ratio of this bottom ash fraction to the refuse combustible fraction on a mass basis is approximately 1:4.5. Thus, an elemental increase greater than this ratio would indicate preferential concentration. In the case of lead, for example, there was a 10-fold increase in concentration in the bottom ash, even after accounting for the mass proportions.

In no case did the elemental concentrations decrease from the refuse to the furnace bottom ash. This is somewhat unusual considering the volatility of several of the elements (As, Sb, Pb, Cd, Br, and Cl). One would expect the greater proportion of these elements to be emitted in the flue gases based solely on their volatility. It is thought that this finding is probably due to the sampling procedure and to the vagaries of hand sorting.

QUENCH WATER

Because water from the bottom ash quench trough is continuously discharged to the municipal sewer system, a grab sample of this effluent (plus a sample of the inlet makeup water) was collected each day and subsequently analyzed for seven water quality parameters. The analyses were selected to provide an indication of potential water pollution problems. The effluent discharge rate was found to be approximately 227 liters/min (60 gal/min). Results of the laboratory analyses are shown in Table 9.

Assessment of these results is difficult because few definitive effluent guidelines exist pertaining to a source of this type. Federal regulations for thermal processing of solid wastes (40 CFR 240) merely state that "all waters discharged from the facility shall be sufficiently treated to meet the most

TABLE 8. ELEMENTAL ANALYSIS OF BOTTOM ASH BY SSMS (μg/g)[a]

Element	Run 1	Run 2	Run 3	Run 3 Duplicate	Average	Range
Uranium	0.11	1.4	< 0.1	0.11	≤ 0.43	< 0.1 - 1.4
Thorium	0.96	1.8	0.12	0.34	0.81	0.12 - 1.8
Bismuth	4.9	22	0.72	5.7	8.3	0.72 - 22
Lead	490	∿ 1,000	31	250	440	31 - ∿ 1,000
Thallium	< 0.1	< 0.22	< 0.17	< 0.1	< 0.15	< 0.72
Mercury	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Gold	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Platinum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Iridium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Osmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhenium	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Tungsten	< 0.48	2.3	0.17	≤ 1.4	≤ 1.1	≤ 0.17 - 2.3
Tantalum	≤ 0.13	1.4	< 0.1	0.45	≤ 0.52	< 0.1 - 1.4
Hafnium	0.55	3.2	< 0.35	≤ 1.4	≤ 1.4	< 0.35 - 3.2
Lutecium	< 0.1	0.16	< 0.1	< 0.66	≤ 0.26	< 0.1 - ≤ 0.66
Ytterbium	≤ 0.34	0.34	< 0.25	< 0.1	≤ 0.26	< 0.1 - 0.34
Thulium	< 0.1	< 0.22	< 0.1	< 0.1	≤ 0.13	< 0.22
Erbium	< 0.12	< 0.67	< 0.22	< 0.29	< 0.33	< 0.67
Holmium	< 0.1	0.17	< 0.1	< 0.26	≤ 0.16	< 0.1 - ≤ 0.26
Dysprosium	0.28	0.94	< 0.1	≤ 0.81	≤ 0.53	< 0.1 - 0.94
Terbium	< 0.1	0.53	< 0.1	≤ 0.31	≤ 0.26	< 0.1 - 0.53
Gadolinium	≤ 1.1	2.6	< 0.14	≤ 3.8	≤ 1.9	< 0.14 - ≤ 3.8
Europium	0.26	0.56	< 0.1	≤ 2.2	≤ 0.78	< 0.1 - ≤ 2.2
Samarium	0.65	1.7	< 0.17	0.65	≤ 0.79	< 0.17 - 1.7
Neodymium	3.6	19	0.45	3.6	6.7	0.45 - 19
Praseodymium	1.9	14	0.36	1.9	4.5	0.36 - 14
Cerium	24	41	3.0	7.2	19	3.0 - 41
Lanthanum	16	27	1.0	3.8	12	1.0 - 27
Barium	630	∿ 2,700	79	> 1%	≥ 3,400	79 - > 10,000
Cesium	0.40	0.86	< 0.1	0.17	≤ 0.38	< 0.1 - 0.86
Iodine	< 0.1	2.9	< 0.13	0.34	≤ 0.87	< 0.1 - 2.9
Tellurium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Antimony	32	69	2.0	16	30	2.0 - 69
Tin	110	200	13	59	96	13 - 200
Indium	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Cadmium	3.8	3.3	0.18	1.6	2.2	0.18 - 3.8
Silver	2.1	13	1.2	2.1	4.6	1.2 - 13
Palladium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhodium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Element	Run 1	Run 2	Run 3	Run 3 Duplicate	Average	Range
Ruthenium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Molybdenum	2.4	26	3.0	1.2	8.2	1.2 - 26
Niobium	4.8	6.4	1.1	4.8	4.3	1.1 - 6.4
Zirconium	31	200	2.2	16	62	2.2 - 200
Yttrium	4.3	8.3	0.55	1.0	3.5	0.55 - 8.3
Strontium	170	640	12	170	250	12 - 640
Rubidium	17	41	4.9	3.9	17	3.9 - 41
Bromine	2.8	32	1.2	4.2	10	1.2 - 32
Selenium	0.66	0.66	0.10	0.22	0.41	0.10 - 0.66
Arsenic	1.7	43	2.7	1.9	12	1.7 - 4.3
Germanium	0.32	1.4	< 0.1	0.10	≤ 0.48	< 0.1 - 1.4
Gallium	1.6	9.9	0.40	1.6	3.4	0.4 - 9.9
Zinc	∿ 1,000	∿ 2,800	92	300	∿ 1,000	92 - ∿ 2,800
Copper	84	∿ 3,400	40	84	∿ 900	40 - ∿ 3,400
Nickel	6.9	130	17	6.9	40	6.9 - 130
Cobalt	3.1	19	1.7	3.1	6.7	1.7 - 19
Iron	∿ 3,000	> 1%	690	∿ 2,000	≥ 3,900	690 - > 10,000
Manganese	170	700	14	110	250	14 - 700
Chromium	160	350	42	34	150	34 - 350
Vanadium	150	43	70	99	90	43 - 150
Titanium	∿ 3,900	> 1%	∿ 1,300	∿ 1,000	≥ 4,000	∿ 1,000 - > 10,000
Scandium	0.81	0.81	0.24	0.71	0.64	0.24 - 0.81
Calcium	> 1%	> 1%	∿ 4,100	> 1%	≥ 8,500	∿ 4,100 - > 10,000
Potassium	720	∿ 4,000	∿ 1,400	410	∿ 1,600	410 - ∿ 4,000
Chlorine	59	360	20	59	120	20 - 360
Sulphur	∿ 1,700	∿ 4,400	580	∿ 2,500	2,300	580 - ∿ 4,400
Phosphorus	610	> 0.5%	500	610	1,700	500 - > 5,000
Silicon	> 1%	> 1%	> 1%	> 0.5%	> 0.9%	> 0.5% - > 1%
Aluminum	> 1%	> 1%	> 0.5%	> 1%	> 0.9%	> 0.5% - > 1%
Magnesium	∿ 2,200	> 0.5%	∿ 2,000	590	≥ 2,400	590 - > 5,000
Sodium	> 0.5%	> 0.5%	∿ 2,800	∿ 1,900	≥ 3,700	∿ 1,900 - > 5,000
Fluorine	21	150	40	16	57	16 - 150
Oxygen	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Nitrogen	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Carbon	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Boron	NR[b]	170	24	18	71[c]	18 - 170[c]
Beryllium	< 0.1	0.69	< 0.1	< 0.1	≤ 0.25	< 0.1 - 0.69
Lithium	24	37	6.9	4.2	18	4.2 - 37

a/ All values in micrograms per gram.

b/ Not reported.

c/ Based on three values.

TABLE 9. WATER QUALITY ANALYSIS OF BOTTOM ASH QUENCH WATER

Test No.	pH		TDS, mg/ℓ		TSS, mg/ℓ		Oil and grease, mg/ℓ		BOD, mg/ℓ		COD, mg/ℓ		Phenols, mg/ℓ	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	7.6	7.6	162	919	0	345	0	16	< 5	69	15	260	< 0.1	< 0.1
2	7.5	8.0	116	554	0	236	1	2	< 3	30	9	125	< 0.1	< 0.1
3	7.6	10.4	190	657	0	184	1	2	< 3	39	29	135	< 0.1	< 0.1
Average	7.6	8.7	156	710	0	255	1	7	< 4	46	18	173	< 0.1	< 0.1

stringent of applicable water quality standards, . . . effective under the Federal Water Pollution Control Act." However, since the Braintree plant's quench water enters the sanitary sewer system, it is more realistic to discuss the quality of the effluent in terms of treatment plant guidelines.

Except for phenols, levels of all the water quality parameters were higher in water effluent than in the makeup water. Phenols could not be detected (< 0.1 mg/liter) in either stream. None of the other constituents measured in this study appeared to be grossly high. Current EPA regulations for secondary treatment plants[4/] are concerned only with pH, TSS, and BOD. No criteria exist for TDS, COD, or oil and grease.

The secondary treatment plant criteria specify that the pH be within a range of 6.0 to 9.0. The pH of the Braintree quench water effluent averaged 8.7 over the 3 day study. TSS and BOD guidelines are both 30 mg/liter. Both parameters in the quench water exceeded this level. The average TSS level was 255 mg/liter, while BOD averaged 46 mg/liter. However, it must be pointed out that this comparison merely indicates the level of treatment that may be required if these same concentrations are found prior to a secondary treatment facility.

ESP INLET

Flue gas samples were taken just prior to the precipitator to determine concentrations of pollutants in the uncontrolled gas stream. Determinations were made for the following constituents:

- Particulate mass emission rate (EPA Method 5);
- Selected trace metal content;
- Elemental composition;
- Particle sizing; and
- O_2 and CO_2.

The Method 5 filtered particulate was originally scheduled to be assayed for PCB and PAH compounds, but an insufficient amount of collected material precluded the analysis. The material was insufficient since parts of the filters were utilized for trace metal (AA) and elemental composition (SSMS) analyses. Results of the completed analyses are summarized in Tables 10 through 12, and are discussed individually below.

TABLE 10. FLUE GAS ANALYSIS - BOILER OUTLET/ESP INLET

Constituent	Run No. 1	Run No. 2	Run No. 3	Average
Particulate				
g/dscm	0.79	0.76	0.91	0.82
kg/hr	27.2	25.3	29.1	27.2
g/MJ heat input	0.67	0.55	0.60	0.60
Trace metals (μg/dscm)				
Sb	490	360	240	360
As	38	54	57	50
Cd	650	320	350	440
Cu	350	450	380	390
Fe	860	740	920	840
Pb	9,200	10,500	15,900	11,900
Hg	14	5	10	10
Elemental composition (see Table 11)				
O_2 (%)	17.0	16.7	--	
CO_2 (%)	4.8	4.8	4.6	
Particle sizing (see Table 12 and Figures 5, 6, and 7)				

TABLE 11. ELEMENTAL ANALYSIS OF ESP INLET, METHOD 5 PARTICULATE, BY SSMS (μg/g)[a]

Element	Run 1	Run 2	Run 2 Duplicate	Run 3	Average	Range
Uranium	< 0.23	0.70	0.58	2.0	≤ 0.88	< 0.23 - 2.0
Thorium	≤ 0.66	≤ 2.4	≤ 9.0	≤ 4.8	≤ 4.2	≤ 0.66 - ≤ 9.0
Bismuth	∿ 1,100	820	820	∿ 1,900	∿ 1,200	820 - 1,900
Lead	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Thallium	2.3	2.3	0.80	1.8	1.8	0.80 - 2.3
Mercury	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/
Gold	0.49	0.20	0.20	0.20	0.27	0.20 - 0.47
Platinum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Iridium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Osmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhenium	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/
Tungsten	11	5.7	6.6	6.6	7.5	5.7 - 11
Tantalum	0.60	0.60	0.90	0.90	0.75	0.60 - 0.90
Hafnium	< 0.79	< 0.79	< 0.79	< 0.79	< 0.79	< 0.79
Lutecium	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13
Ytterbium	< 0.66	< 0.66	< 0.66	< 0.66	< 0.66	< 0.66
Thulium	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
Erbium	< 0.34	< 0.34	< 0.33	< 0.34	< 0.34	< 0.34
Holmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Dysprosium	< 0.15	< 0.15	< 0.14	< 0.15	< 0.15	< 0.15
Terbium	< 0.1	< 0.1	< 0.1	< 0.10	< 0.1	< 0.1
Gadolinium	< 0.38	< 0.38	< 0.37	< 0.38	< 0.38	< 0.38
Europium	< 0.15	< 0.15	< 0.14	< 0.15	< 0.15	< 0.15
Samarium	4.3	1.7	1.8	1.4	2.3	1.4 - 4.3
Neodymium	7.3	7.3	7.3	13	8.7	7.3 - 13
Praseodymium	4.0	3.5	8.1	3.5	4.8	3.5 - 8.1
Cerium	31	15	31	11	22	11 - 31
Lanthanum	11	5.5	21	5.5	11	5.5 - 21
Barium	540	270	270	540	400	270 - 540
Cesium	≤ 3.7	≤ 3.7	≤ 3.7	≤ 3.7	≤ 3.7	≤ 3.7
Iodine	37	37	17	37	32	17 - 37
Tellurium	2.0	1.4	0.72	2.0	1.5	0.72 - 2.0
Antimony	∿ 4,100	∿ 2,300	∿ 1,400	∿ 1,000	∿ 2,200	1,000 - 4,100
Tin	> 5,000	∿ 2,600	> 5,000	∿ 4,400	≥ 4,200	2,600 - > 5,000
Indium	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/
Cadmium	∿ 2,200	770	770	770	1,100	770 - 2,200
Silver	200	200	150	110	165	110 - 200
Palladium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhodium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Element	Run 1	Run 2	Run 2 Duplicate	Run 3	Average	Range
Ruthenium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Molybdenum	51	51	18	51	43	18 - 51
Niobium	3.2	6.4	4.8	3.2	4.4	3.2 - 6.4
Zirconium	37	37	32	17	31	17 - 37
Yttrium	5.6	3.7	3.7	5.6	4.6	3.7 - 5.6
Strontium	280	28	59	20	97	20 - 280
Rubidium	380	75	75	150	170	75 - 380
Bromine	∿ 2,400	420	650	650	1,000	420 - 2,400
Selenium	≤ 94	≤ 19	≤ 13	≤ 27	≤ 38	≤ 13 - ≤ 94
Arsenic	130	130	130	92	120	92 - 130
Germanium	33	7.7	7.7	1.6	12	1.6 - 33
Gallium	28	49	49	28	38	28 - 49
Zinc	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Copper	∿ 3,400	∿ 1,500	∿ 1,500	∿ 1,000	∿ 1,800	1,000 - 3,400
Nickel	INT[c]/	INT[c]/	INT[c]/	INT[c]/	NR[b]/	NR[b]/
Cobalt	100	20[d]/	19[d]/	13[d]/	38[d]/	13 - 100[d]/
Iron	> 5,000	> 5,000	∿ 1,200	∿ 3,400	∿ 3,600	1,200 - 5,000
Manganese	760	∿ 1,400	490	420	770	420 - 1,400
Chromium	560	260	200	47	270	47 - 560
Vanadium	64	28	21	43	39	21 - 64
Titanium	> 1%	> 0.5%	∿ 0.37%	> 0.5%	≥ 0.6%	0.37% - > 1%
Scandium	< 0.13	0.17	0.17	< 0.13	≤ 0.15	< 0.13 - 0.17
Calcium	> 1%[e]/	> 1%[e]/	> 0.5%[e]/	> 0.5%[e]/	> 0.75%[e]/	> 0.5% - > 1%[e]/
Potassium	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Chlorine	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Sulphur	INT[c]/	INT[c]/	INT[c]/	INT[c]/	NR[b]/	NR[b]/
Phosphorus	> 5,000	∿ 4,400	∿ 3,300	5,000	≥ 4,400	3,300 - > 5,000
Silicon	> 1%[e]/	> 1%[e]/	> 1%[e]/	> 1%[e]/	> 1%[e]/	> 1%
Aluminum	> 1%[e]/	> 1%[e]/	> 0.5%[e]/	> 1%[e]/	> 0.9%	> 0.5% - > 1%[e]/
Magnesium	∿ 4,900[e]/	∿ 4,500[e]/	∿ 3,200[e]/	∿ 3,100[e]/	∿ 3,900[e]/	3,100 - 4,900[e]/
Sodium	> 0.5%[e]/	> 0.5%[e]/	∿ 0.29%[e]/	> 1%[e]/	≥ 0.57%[e]/	0.29% - > 1%[e]/
Fluorine	> 10,000	∿ 3,500	∿ 3,500	∿ 1,600	≥ 4,600	1,600 - > 10,000
Oxygen	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/
Nitrogen	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/
Carbon	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/	NR[b]/
Boron	220[d]/	7[d]/	120[d]/	41[d]/	120[d]/	41 - 220[d]/
Beryllium	< 0.15	< 0.15	< 0.14	< 0.15	< 0.15	NR[b]/
Lithium	43	76	43	120	70	43 - 120

a/ All values in micrograms per gram except where noted.

b/ Not reported.

c/ Interference by a major component spectrum.

d/ Values corrected for background contribution > 10% of the sample value.

e/ Values unreliable due to background levels greater than the quantitative analysis range.

TABLE 12. SUMMARY OF BRINK IMPACTOR RESULTS

Collection stage	50% Particle cutoff diameter (D_{p50}, μm)[a]					Geometric mean diameter (avg.)
	Runs 1&2	Runs 3&4[b]	Run 6	Run 7	Average	
Cyclone	7	7	7	7	7	--
1	3.58	3.55	3.62	3.63	3.58	5.01
2	2.10	2.08	2.12	2.12	2.10	2.74
3	1.42	1.40	1.43	1.43	1.42	1.72
4	0.72	0.72	0.73	0.73	0.72	1.01
5	0.43	0.43	0.43	0.43	0.43	0.56

Collection stage	Percent by weight							Cumulative percent less than Dp (avg.)
	Run 1	Run 2	Run 3	Run 4[b]	Run 6	Run 7	Average	
Cyclone	37.33	5.48	38.02	43.00	2.88	35.11	26.97	73.03
1	0.64	7.08	4.61	4.75	1.52	5.48	4.85	68.18
2	2.86	6.55	7.27	0.91	41.10	11.86	11.76	56.42
3	2.73	18.79	5.50	7.66	48.71	6.14	14.92	41.50
4	12.46	17.06	19.69	13.02	1.38	4.55	11.36	30.14
5	43.98	33.96	15.26	19.58	3.40	17.70	22.31	7.83
Final filter	0.00	11.07	9.64	6.08	1.02	19.17	7.83	--

Collection stage	Percent by weight omitting cyclone							Cumulative percent less than Dp (avg.)
	Run 1	Run 2	Run 3	Run 4[b]	Run 6	Run 7	Average	
1	1.02	7.49	7.44	17.10	1.56	8.44	7.18	92.82
2	4.56	6.93	11.73	1.60	42.32	18.28	14.24	78.58
3	4.36	19.88	8.87	13.44	50.15	9.45	17.69	60.99
4	19.88	18.05	31.77	22.84	1.42	7.01	16.83	44.06
5	70.18	35.93	24.62	34.35	3.50	27.28	32.64	11.42
Final filter	0.00	11.72	15.57	10.67	1.05	29.54	11.42	--

a/ D_{p50} = particle cutoff diameter at 50% collection efficiency for each stage of the Brink impactor.

b/ Run No. 5 was discarded in the field due to mishandling of the Brink.

Note: Sample illustration: The average cutoff diameter for Stage 5 is 0.43 μm (from top of table). From the middle section of the table, 22.3% of the total sample weight is composed of particles between 0.43 and 0.72 μm (Stages 4 and 5).

Particulate Concentration

Concentrations of particulates in the incinerator exhaust gases were established through the use of a standard EPA Method 5 sampling train. Chemical characterization of the particulate captured on the filters was subsequently carried out, as discussed in the next subsection.

The particulate concentration values shown in Table 10 represent "total" particulate, which includes both filterable and condensible particulate. An average concentration of 822 mg/dscm resulted from the three sampling runs. On a heat input basis, the average concentration was found to be 0.60 g/MJ (1.4 lb/10^6 Btu).

The condensible particulate fraction amounted to about 4% of the total particulate catch, or an average of 36.3 mg/dscm. Approximately 6.7% of impinger catch was organically extractable weight.

Elemental Composition

Analysis of the particulate filters by AA for seven specific trace metals and by SSMS for general elemental composition was performed on each of the three Method 5 samples.

The AA analysis (Table 10) revealed a high particulate lead content, averaging 11,900 μg/dscm. Arsenic and mercury, two volatile metals, were found to be present in concentrations less than 60 μg/dscm. Concentrations of the other metals (Sb, Cd, Cu, and Fe) were in the range of 360 to 840 μg/dscm. These levels of Sb and Cd may be of some concern because of their higher toxicity.

SSMS results (Table 11) confirmed the more accurate AA values. Other elements, which were not included in the AA analysis but which showed relatively high concentrations by SSMS included Bi, Sn, Ti, K, and P. Somewhat elevated levels of the halides, Cl, Br, and F, were also reported.

Particle Sizing

Results of the inlet particle sizing tests (Brink impactor) are tabulated in Table 12. Figures 5 through 7 are graphical representatives of these data. A total of six impactor runs were made, two each test day. Run No. 5 was voided after it was found that the sample integrity had been jeopardized and another run was added to bring the total to six.

The data in Table 12 suggest that about 56% of the particulate is smaller than 2.1 μm. Only 4.9%, by weight, was found on the next larger stage (3.6 μm), while 27% was collected by the cyclone (> 7 μm).

Inlet particulate sizing results were very erratic. There was no reproducible loading on any single stage of the impactor upon comparison of the six runs (see Figure 6).

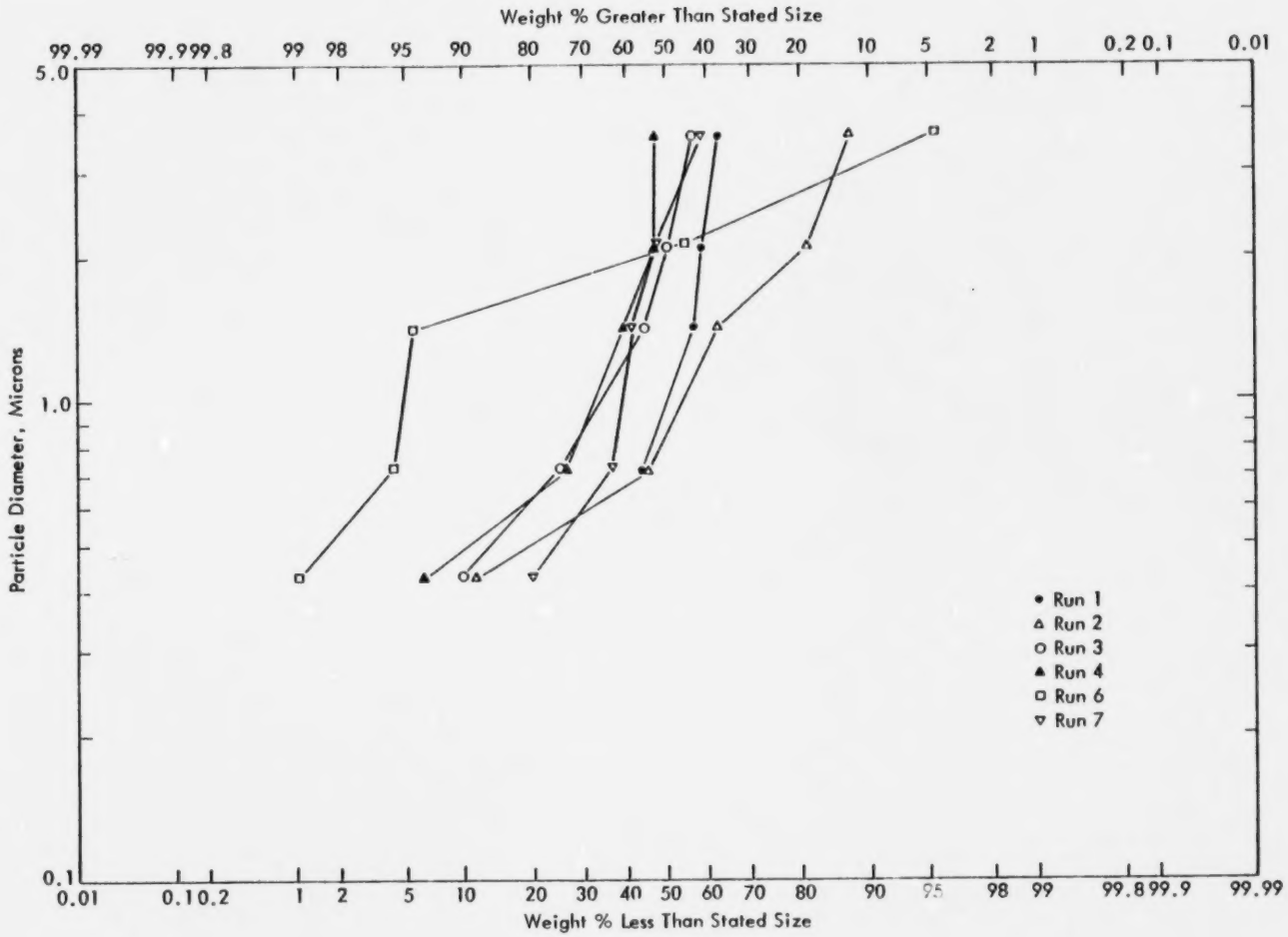

Figure 5. Particle diameter versus weight percent less/greater than stated size (inlet).

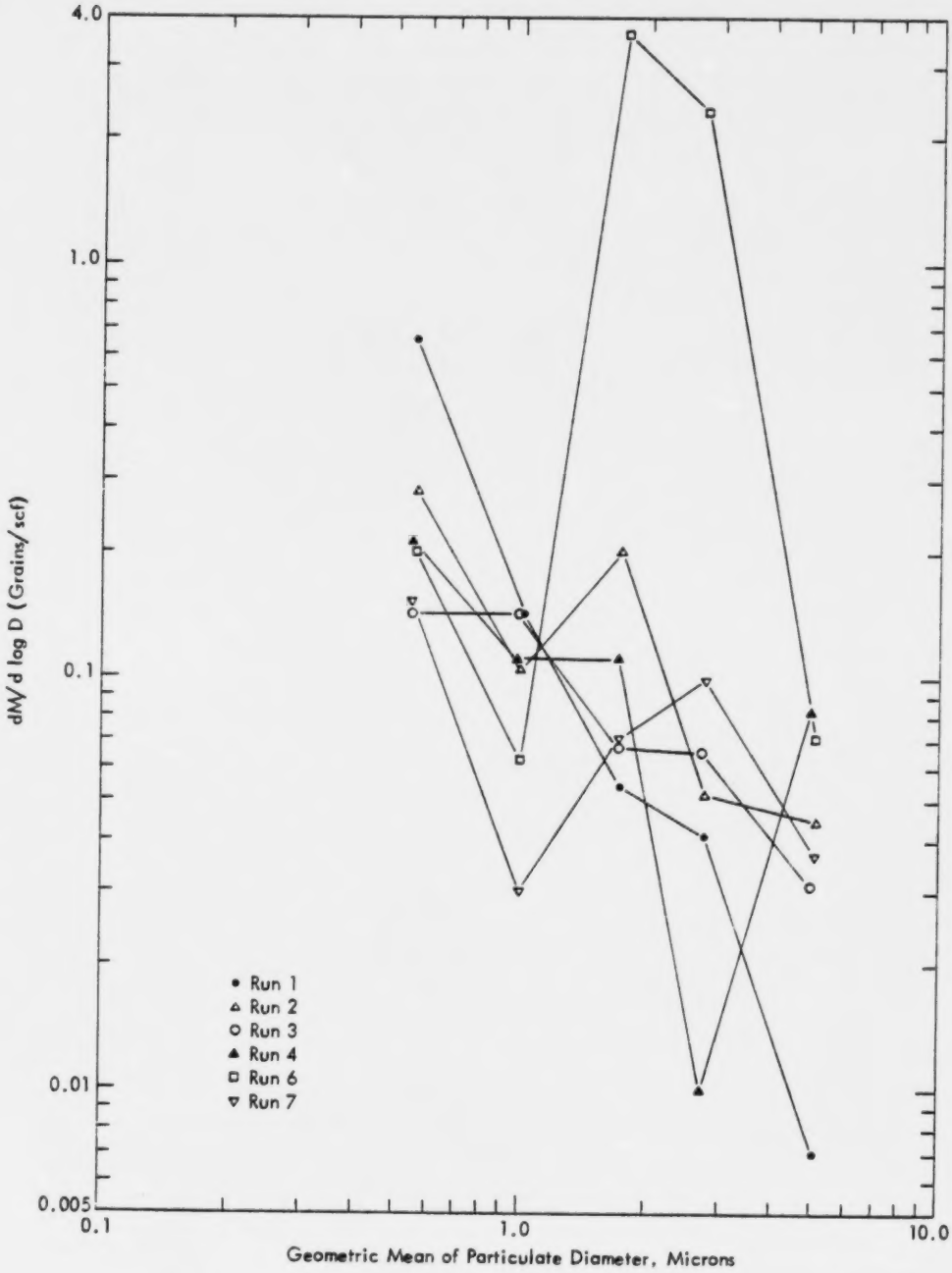

Figure 6. Differential stage loadings (inlet).

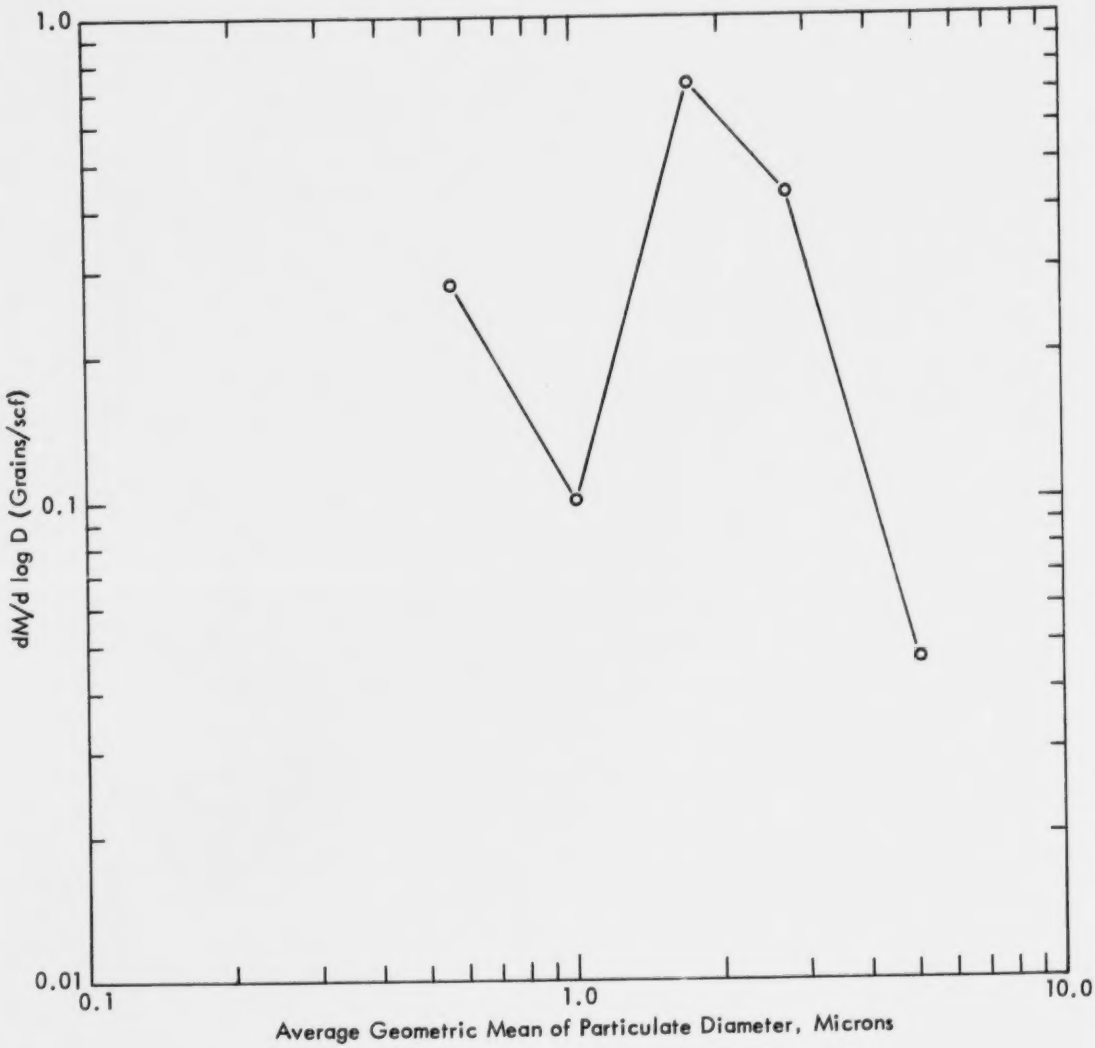

Figure 7. Average differential stage loadings (inlet).

Also, the general slope of the curves in Figure 6 indicate a reduction in grain loading as the particle size increases. The opposite relationship would be more expected.

The erratic nature of the size distributions are believed to result from the random size and density of the particulate leaving the furnace. Particulate from refuse incineration may span several orders of magnitude (e.g., 0.1 to 10,000 μm). When this particulate encountered the 2 mm diameter nozzle used on the Brink impactor for this study, several phenomena might have occurred: (a) very large particulate could have impacted the edge of the nozzle and either escaped collection or broken into smaller fragments to be collected; (b) small particulate (1 to 5 μm) with low density would be collected on the appropriate Brink stages; or (c) small particulate with high density could have been collected on the first stages of the impactor rather than the lower stages which would correspond more closely to their actual size. Since the Brink impactor is an aerodynamic sizing device capable of classifying equivalent density particulate within a band width of about 0.4 to 4.0 μm, erratic results can be encountered if the Brink is used to sample random density particulate with a size range much greater than the band width (0.4 to 4 μm). Furthermore, the basic shape of particulate emitted from refuse incineration, large and flake-like rather than approaching spherical, does not lend itself to aerodynamic collection. Finally, the heterogeneous nature of the refuse being burned can contribute to varying results from run to run.

In summary, the inlet particulate size data cannot be interpreted in any meaningful way. It is also suggested that, in further studies on refuse incinerators, a different method of particulate sizing be used to avoid the problems encountered in this study.

Gas Composition

Oxygen content of the flue gases at the ESP inlet averaged 16.8%. This value is fairly high for a refuse incinerator and reflects the large amount of excess air used in the Braintree system (> 400%). The range of percent O_2 reported at other municipal incinerators is 8.5 to 18.7% (see Table 16).

The CO_2 content, which is influenced by the percentage of O_2 in the flue gases, was low, averaging 4.8%.

ESP ASH

Daily grab samples of the fly ash collected by the ESP were analyzed in the laboratory for the following constituents:

- Leachable anions (Cl^-, F^-, Br^-, CN^-, $SO_4^=$, and NO_3^-);
- PCB and PAH compounds; and
- Elemental composition.

Resulting data are presented in Tables 13 and 14. Quality assurance data for the anion and SSMS analyses are included in Appendix A.

The rate of collection of fly ash in the precipitator was calculated from the inlet/outlet Method 5 particulate sampling results. The ash capture rates determined by this method were 17.1, 16.6, and 23.9 kg/hr for the three runs, respectively. The average rate was 19.2 kg/hr.

Anions

The anion analyses revealed high levels of chlorides and sulfates, and negligible amounts of cyanides and nitrates. Chloride concentrations were high, averaging 41,000 μg/g, while sulfate levels were about 10,400 μg/g. Concentrations of CN^- and NO_3^- were both below the limits of detection (see Table 13). Fluoride and bromide determinations showed relatively low levels of these halides in the ESP ash.

Elemental Composition

SSMS data from the elemental composition analysis of the ESP ash is tabulated in Table 14. Several elements were present in concentrations greater than 1% (the upper limit of detection for SSMS). These were Ca, K, Cl, P, Si, Al, Mg, and Na. Other elements prevalent in the ESP ash included Pb, Sn, Zn, Fe, Mn, Ti, and F. It should be noted that the SSMS results for Cl and F are total concentrations, unlike the AA results which reflect leachable quantities only.

PCB and PAH

The presence of PCB materials could not be confirmed in the samples of ESP ash. The samples were initially screened by electron-capture GC, but PCB levels were not clearly observed above the instrumental detection limits. Aliquots of the samples were then derivatized to form decachlorobiphenyl (DCB) to provide improved GC sensitivity. The subsequent GC responses could not be attributed solely to PCB materials without structural confirmation (extensive additional work with mass spectroscopy).

PAH materials were not observed above the instrumental detection limit (0.2 to 3 μg/g) for any of the ESP ash samples.

TABLE 13. ESP ASH ANALYSIS

Constituent	Run No. 1	Run No. 2	Run No. 3	Average
Anions (μg/g)				
Cl^-	69,000	41,000	14,000	41,000
F^-	590	780	370	580
Br^-	790	480	280	520
CN^-	< 0.7	< 0.7	< 0.7	< 0.7
$SO_4^=$	12,000	14,000	5,200	10,400
NO_3	< 5	< 5	< 5	< 5

Elemental analysis (see Table 4-11)

PCB (μg/g as DCB) Below EC/GC detection limit (0.4 ng/g)

	Run No. 1	Run No. 2	Run No. 3	Detection limit (μg/g)[a]
Acenaphthylene	ND[b]	ND	< 0.3[d]	0.3
Fluorene	ND	ND	ND	0.5
Phenanthrene	ND	< 0.4	< 0.4	0.4
Anthracene	ND	ND	< 0.5	0.5
Fluoranthrene	ND	ND	ND	1
Pyrene	ND	ND	< 0.7	0.7
1,2-Benzanthracene	ND	ND	ND	0.2
Chrysene	ND	ND	ND	1
Benzo e pyrene	ND	ND	ND	0.3
Benzo a pyrene	ND	ND	ND	0.6
Perylene	ND	ND	ND	2
Indeno(1,2,3-C,D)pyrene	ND	ND	ND	3
1,12-Benzoperylene	ND	ND	ND	NR[c]
1,2,5,6-Dibenzanthracene	ND	ND	ND	NR

a/ Based on a 10-g sample weight and assuming a minimum response of 1,000 counts.

b/ Not detected at or above instrumental detection limit.

c/ Not reported due to insufficient standard concentration for reliable response factor calculation.

d/ "Less than" values indicate samples and materials which produced observable responses below the range of reliable quantitative analysis.

TABLE 14. ELEMENTAL ANALYSIS OF ESP ASH BY SSMS (μg/g)[a]

Element	Run 1	Run 2	Run 3	Run 3 Duplicate	Average	Range
Uranium	0.87	0.58	0.58	1.2	0.81	0.58-1.2
Thorium	2.4	4.2	0.93	< 0.17	≤ 1.9	< 0.17-4.2
Bismuth	130	75	7.5	18	58	7.5-130
Lead	> 0.5%	> 1%	∿ 0.20%	∿ 0.20%	≥ 0.5%	∿ 0.2%- > 1%
Thallium	0.60	< 0.12	< 0.12	< 0.12	≤ 0.24	< 0.12-0.60
Mercury	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Gold	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Platinum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Iridium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Osmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhenium	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Tungsten	5.3	12	2.5	5.3	6.3	2.5-12
Tantalum	0.70	1.4	0.84	0.42	0.84	0.42-1.4
Hafnium	2.1	3.5	0.70	2.1	2.1	0.70-3.5
Lutecium	≤ 4.0	≤ 0.80	≤ 0.40	≤ 0.80	≤ 1.5	≤ 0.40- ≤ 4.0
Ytterbium	2.1	0.89	0.64	1.0	1.2	0.64-2.1
Thulium	0.41	0.21	0.17	0.24	0.26	0.17-0.41
Erbium	0.64	0.64	0.53	1.1	0.73	0.53-1.1
Holmium	0.39	0.33	0.17	0.58	0.37	0.17-0.58
Dysprosium	1.4	1.4	1.2	2.2	1.6	1.2-2.2
Terbium	0.38	0.51	0.25	0.51	0.41	0.25-0.51
Gadolinium	1.4	1.9	0.93	1.9	1.5	0.93-1.9
Europium	0.72	0.72	0.36	0.72	0.63	0.36-0.72
Samarium	6.2	2.9	1.4	2.9	3.4	1.4-6.2
Neodymium	6.8	14	5.8	10	9.2	5.8-14
Praseodymium	4.0	5.4	2.7	4.0	4.0	2.7-5.4
Cerium	83	83	31	62	65	31-83
Lanthanum	12	33	5.5	12	16	5.5-33
Barium	880	∿ 1,200	320	∿ 1,200	900	320- ∿ 1,200
Cesium	1.6	1.0	0.52	0.52	0.91	0.52-1.6
Iodine	6.4	7.7	3.9	3.9	5.5	3.9-7.7
Tellurium	0.29	0.29	< 0.12	< 0.12	≤ 0.21	< 0.12-0.29
Antimony	780	210	39	39	270	39-780
Tin	∿ 3,400	920	250	250	1,200	250- ∿ 3,400
Indium	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Cadmium	93	44	9.3	2.2	37	2.2-93
Silver	34	34	7.3	7.3	21	7.3-34
Palladium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhodium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Element	Run 1	Run 2	Run 3	Run 3 Duplicate	Average	Range
Ruthenium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Molybdenum	87	130	17	37	68	17-130
Niobium	24	32	14	24	24	14-32
Zirconium	0.30	200	55	110	91	0.3-200
Yttrium	11	6.2	1.4	6.2	6.2	1.4-11
Strontium	240	340	160	430	290	160-430
Rubidium	56	31	17	31	34	17-56
Bromine	490	490	100	60	280	60-490
Selenium	16	4.0	1.9	1.9	6.0	1.9-16
Arsenic	41	7.6	8.7	4.1	15	4.1-41
Germanium	1.4	2.8	2.8	2.8	2.4	1.4-2.8
Gallium	8.4	8.4	1.8	4.2	5.7	1.8-8.4
Zinc	> 0.5%	> 1%	> 0.5%	∿ 0.2%	≥ 0.5%	0.2%- > 1%
Copper	∿ 1,200	840	280	560	720	280- ∿ 1,200
Nickel	460	100	120	120	200	100-460
Cobalt	210	38	12	14	68	12-210
Iron	> 1%	> 0.5%	> 0.5%	> 1%	> 0.75%	> 0.5%- > 1%
Manganese	∿ 2,800	∿ 1,000	∿ 1,400	∿ 1,400	∿ 1,600	∿ 1,000- ∿ 2,800
Chromium	∿ 1,200	580	31	420	560	31- ∿ 1,200
Vanadium	92	110	58	160	100	58-160
Titanium	> 0.5%	0.032%	> 0.5%	> 1%	≥ 0.5%	0.032%- > 1%
Scandium	2.7	2.7	1.3	6.3	3.2	1.3-6.3
Calcium	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Potassium	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Chlorine	> 1%	> 1%	> 1%	> 0.5%	> 0.9%	> 0.5%- > 1%
Sulfur	> 0.5%	> 1%	> 1%	∿ 0.48%	≥ 0.75%	0.48%- > 1%
Phosphorus	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Silicon	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Aluminum	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Magnesium	> 1%	> 1%	> 1%	> 0.5%	> 0.9%	> 0.5%
Sodium	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Fluorine	∿ 3,500	∿ 1,700	830	620	1,700	620-3,500
Oxygen	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Nitrogen	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Carbon	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Boron	180	230	230	500	285	180-500
Beryllium	0.60	0.60	< 0.18	0.60	≤ 0.50	< 0.18-0.60
Lithium	86	100	120	290	150	86-290

a/ All values in micrograms per gram except where noted.

b/ NR - not reported.

AIR EMISSIONS - ESP OUTLET

Characterization of the final air emissions from the Braintree incinerator was a major part of the overall environmental assessment. Extensive sampling and analysis of the effluent was therefore carried out. Parameters measured during the test program included the following:

- Gas composition (O_2, CO_2, NO_x, SO_2, HC and CO);
- Particulate concentration (Method 5);
- Characterization of particulate for elemental composition and specific trace metals;
- Particle sizing (Andersen impactor);
- Carbonyls;
- Vaporous mercury;
- Leachable anions (Cl^-, F^-, Br^-, and CN^-); and
- SASS train (EPA Level 1 assessment).

The results of these analyses are discussed individually in the following subsections.

Gas Composition

With the exception of CO_2, the gaseous constituents of the flue gas, as shown in Table 15, were monitored with continuous analyzers. These analyzers were run during the entire test period, each day.

Levels of CO_2 remained low during the test program, averaging 5% or less. The concentration of O_2 in the exhaust gases was relatively high. O_2 levels ranged from 13.9% to as high as 18.1% over the course of the test program. These levels reflect the large amounts of excess air used in the Braintree incinerator. Based on the reported O_2 and CO_2 levels at the boiler outlet (inlet to the ESP), it was calculated that the percent excess air was more than 400%. Since no overfire was administered to the incinerator firebox during the tests by MRI, the high excess air was most likely the result of the underfire air fed to the burning refuse bed.

In the context of the above discussion, it is surprising that the CO concentrations were as high as those measured by the CO analyzer. CO levels ranged

TABLE 15. INCINERATOR EXHAUST GAS COMPOSITION

Test No.	Percent moisture[a]	CO_2[b] (%)	O_2 (%)[c]		CO (ppm)[c]		HC (ppm)[c,d]		NO_x (ppm)[c]		SO_2 (ppm)[c]	
			Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
1	5.4	5.0	13.9-18.1	16.2	309-644	488	6.7-22.7	12.2	38-76	55	5-90	45
2	6.5	4.1	14.0-16.4	15.4	378-747	501	2.5-20.5	9.3	37-71	56	15-151	44
3	7.1	3.6	15.9-17.9	16.7	211-623	432	8.8-16.1	12.5	30-64	50	23-126	54

a/ Moisture based on amount of condensate collected in particulate emission tests.

b/ CO_2 based on average of three replicate tests done three times each day with Fyrite analyzer.

c/ O_2, NO_x, CO, HC and SO_2 measured with continuous analyzers.

d/ HC reported is total nonmethane HC.

between 211 and 747 ppm, and averaged 488, 501, and 432 ppm during the 3 days of sampling. The origin of this amount of CO is unclear but it may have resulted from lack of overfire air.

The remaining gaseous pollutants measured were total hydrocarbons, NO_x, and SO_2, and were found at very low levels. These constituents are normally low in typical refuse combustion emissions. Because the EPA and State of Massachusetts regulations specify only particulate effluent limitations from municipal incinerators, it is not possible to assess the values in Table 15 on the basis of established emission standards. Therefore, the alternative is to compare these concentrations to data gathered from other incineration systems. A tabulation of such data has been prepared by MRI and is shown in Table 16. It appears that all of the gaseous pollutant levels measured at the Braintree incinerator fall within the stated ranges, with the exception of CO.

Particulate Concentration

Particulate concentrations in the final air emissions are tabulated in Table 17. Results include a differentiation between filterable and condensible particulate ("front half" and "back half" of the Method 5 sampling train). Total particulate concentrations averaged 215.0 mg/dscm (0.094 gr/dscf) for the three sampling runs. Of this total, 190.9 mg/dscm was dry, filterable particulate, while 24.1 mg/dscm was captured in the impingers. The organic extractable portion of the impinger catch averaged 1.96 mg/dscm.

Federal regulations limiting particulate emissions from municipal incinerators specify a ceiling value of 0.18 g/dscm (0.08 gr/dscf), corrected to 12% CO_2. State of Massachusetts emission regulations are slightly more lenient, allowing up to 0.23 g/dscm (0.10 gr/dscf) at 12% CO_2. Although the average concentration (corrected to 12% CO_2) measured by MRI was 0.55 g/dscm (0.24 gr/dscf), this should not be construed to imply that the incinerator was out of compliance with particulate emission regulations. This statement is made because EPA compliance tests conducted by another contractor in November 1977 and June 1978 both showed compliance with the applicable regulations (see Section 6). In both instances, "proper" incinerator operation was maintained by personnel from Metcalf and Eddy, Inc., and the boiler-ESP configuration was different from that used during the MRI tests since the other tests did not include inlet sampling. Further discussion of these compliance tests is contained in Section 6.

Table 18 presents a complete summary of the inlet and outlet particulate sampling results, including results expressed in terms of both filterable and total particulate concentrations. Table 19 presents the same results in English units. A most important value shown in this table is the ESP efficiency, which appears beneath the particulate results. The measured efficiencies, which averaged 73.6% for the three tests, are very low for this precipitator and for ESPs in general. Design collection efficiency was stated to be 93% for this unit.

TABLE 16. DATA SUMMARY OF FLUE GAS EMISSION CONCENTRATIONS FROM MASS BURN INCINERATORS[a,b,c,d]

Gaseous species	Concentration range[e]
CO_2%	1.2-12.0
O_2%	8.5-18.7
H_2O%	4.8-12.3
HCl (ppm)	63-1,260
SO_2 (ppm)	22-195
NO_x (ppm)	4-177
CO (ppm)	6.1-179
Total hydrocarbon (ppm)	25.5-42.5
Aldehydes (ppm)	0.15-1.06

a/ Bozeka, C. G., Nashville Incinerator Performance Tests. Presented at the 1976 National Waste Processing Conference, Boston, MA, May 1976.

b/ Carotti, A. A., and E. R. Kaiser. Concentrations of Twenty Gaseous Chemical Species in the Flue Gas of Municipal Incinerator. J. of Air Pol. Contr. Assoc., 22(4):248-253, April 1972.

c/ Kaplaun, L., and P. Franconeri. Determination and Evaluation of Stack Emissions from Municipal Incinerators. Presented at the 68th Annual Meeting of the Air Pollution Control Association, Boston, MA, June 1975.

d/ Vaughan, D. A. et al. Fireside Corrosion in Municipal Incinerators Versus PVC Content of the Refuse. Presented at the 1974 National Incinerator Conference, Miami, FL, May 1974.

e/ Data are actual data (not corrected to 12% CO_2).

TABLE 17. INCINERATOR FLUE GAS PARTICULATE DATA (After ESP)

Test No.	Stack gas flow rate (dNm^3/min)	Average stack temperature (°C)	Front half (mg/dscm)[a/] SASS[c/]	Front half (mg/dscm)[a/] Method 5	Method 5 back half[b/] (mg/dscm) Organic extract	Method 5 back half[b/] (mg/dscm) H_2O Evaporation	Total Method 5 (mg/dscm)
1	742	197	--	178.4	2.96	24.35	205.7
2	577	192	137.5	207.3	1.87	22.20	231.3
3	456	204	--	186.4	1.06	19.71	207.2
Average	592	198	--	190.9	1.96	22.09	215.0

a/ "Front half" refers to filter catch plus acetone rinse of probe, etc.

b/ "Back half" refers to CCl_4 extraction of organics in impinger water from inorganics remaining in the impinger water.

c/ SASS is the high volume Source Assessment Sampling System that was used for one run during the second day. Its operation provides front half particulate results.

TABLE 18. PARTICULATE RESULTS IN METRIC UNITS

Run No.	1		2		3		Average	
Date	1/17/78		1/18/78		1/19/78			
Sampling location	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Volume of gas sampled, dscm[a]	1.869	4.263	1.996	3.590	2.041	2.831	1.969	3.561
Percent moisture by volume	6.2	5.4	7.4	6.5	9.0	7.1	7.5	6.3
Average stack gas temperature, °C	251.5	197.0	234.3	192.0	259.2	204.1	248.3	197.7
Stack gas volumetric flow rate, dscmm	571.1	741.6	554.4	576.6	532.8	456.2	552.8	591.4
Stack gas volumetric flow rate, acmm	1077.3	1238.4	1052.3	990.5	1057.8	792.1	1062.5	1007.0
Percent isokinetic	86.1	92.3	94.7	100.0	100.7	99.7	93.8	97.3
Refuse feed rate, Mg/hr	4.7	4.7	4.6	4.6	4.1	4.1	4.5	4.5
Heat input, 10^9 Joule/hr	40.5	40.5	46.0	46.0	49.0	49.0	45.2	45.2
Particulate-probe and filter								
mg[b]	1371.5	762.1	1430.0	745.8	1858.3	530.2	1553.3	679.4
mg/dscm[b]	732.13	178.40	715.09	207.30	908.71	186.41	785.31	190.87
mg/acm[b]	388.11	106.83	376.73	120.68	457.70	107.65	407.51	111.72
kg/hr[b]	25.082	7.937	23.781	7.170	29.045	5.115	25.969	6.741
kg/Mg feed[b]	5.336	1.689	3.836	1.156	7.084	1.247	5.419	1.364
g/MJ-heat input	0.619	0.196	0.517	0.156	0.593	0.104	0.575	0.149
Particulate-total								
mg	1485.1	878.5	1520.1	832.2	1864.6	589.0	1623.3	766.6
mg/dscm	792.77	205.65	760.14	231.31	911.79	207.64	821.57	214.87
mg/acm	420.26	123.15	400.47	134.66	459.25	119.59	426.66	125.80
kg/hr	27.159	9.149	25.280	8.001	29.144	5.682	27.194	7.611
kg/Mg feed	5.778	1.946	4.077	1.290	7.100	1.386	5.631	1.541
g/MJ-heat input	0.671	0.226	0.550	0.179	0.595	0.116	0.602	0.168
Percent impinger catch	7.65	13.25	5.93	10.38	0.34	9.98	4.64	11.20
ESP efficiency (%)[c]	74.1		69.6		77.2		73.6	

a/ Dry standard cubic meter at 20°C and 760 mm Hg.

b/ mg = milligrams
mg/dscm = milligrams per dry standard cubic meter
mg/acm = milligrams per actual cubic meter
kg/hr = kilograms per hour
kg/Mg feed = kilograms per Megagram feed

c/ Using mg/dscm of the total particulate results as the base for the efficiency calculations.

TABLE 19. PARTICULATE RESULTS IN ENGLISH UNITS

Run No.	1		2		3			
Date	1/17/78		1/18/78		1/19/78		Average	
Sampling location	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Volume of gas sampled, dscf[a]	66.02	150.54	70.47	126.79	72.07	99.97	69.52	125.77
Percent moisture by volume	6.2	5.4	7.4	6.5	9.0	7.1	7.5	6.3
Average stack gas temperature, °F	484.8	386.6	453.8	377.7	498.5	399.5	429.0	387.9
Stack gas volumetric flow rate, dscfm	20,167	26,190	19,577	20,362	18,816	16,610	19,520	21,054
Stack gas volumetric flow rate, acfm	38,043	43,734	37,160	34,977	37,357	27,971	37,520	35,561
Percent isokinetic	86.1	92.3	94.7	100.0	100.7	99.7	93.8	97.3
Refuse feed rate, ton/hr	5.2	5.2	5.1	5.1	4.5	4.5	4.9	4.9
Heat input, 10^6 Btu/hr	38.5	38.5	43.8	43.8	45.2	45.2	42.8	42.8
Particulate-probe and filter								
mg[b]	1371.5	762.1	1430.0	745.8	1858.3	530.2	1553.3	679.4
gr/dscf[c]	0.31994	0.07796	0.31249	0.09049	0.39710	0.08168	0.34318	0.08341
gr/acf[c]	0.16960	0.04669	0.16463	0.05274	0.20001	0.04704	0.17808	0.04882
lb/hr[d]	55.30	17.50	52.43	15.81	64.03	11.28	57.25	14.86
lb/ton-feed[d]	10.635	3.365	7.710	2.325	14.229	2.507	10.858	2.732
lb/10^6 Btu-heat input	1.436	0.455	1.197	0.361	1.386	0.244	1.338	0.347
Particulate-total								
mg	1485.1	878.5	1520.1	832.2	1864.6	589.0	1623.3	766.6
gr/dscf	0.34644	0.08987	0.33218	0.10108	0.39845	0.09074	0.35902	0.09390
gr/acf	0.18365	0.05382	0.17501	0.05884	0.20069	0.05226	0.18645	0.05497
lb/hr	59.88	20.17	55.73	17.64	64.25	12.53	59.95	16.78
lb/ton-feed	11.515	3.879	8.195	2.594	14.278	2,784	11.329	3.086
lb/10^6 Btu-heat input	1.555	0.524	1.272	0.403	1.391	1.662	1.401	0.392
Percent impinger catch	7.65	13.25	5.93	10.38	0.34	9.98	4.64	11.20
ESP efficiency (%)[e]	74.1		69.6		77.2		73.6	

a/ Dry standard cubic ft at 68°F and 29.92 in Hg.

b/ Milligrams

c/ gr/dscf = grains per dry standard cubic foot
gr/acf = grains per actual cubic foot

d/ Pounds per hour
Pounds per ton-feed

e/ Using gr/dscf of the total particulate results as the base for the efficiency calculations.

The cause of this reduced efficiency is not clear. The outlet concentration measured by MRI was much higher than particulate levels reported for the compliance tests conducted in November 1977. During the MRI sampling, several process parameters differed from those recorded during the compliance tests. Grate speeds were higher, especially that of the feed stoker. The ID fan speed was also greater, producing a larger flue gas volume flow rate. Stack flow rates measured by MRI averaged about 1,007 acmm at 198°C, while design flow rate through the precipitator is 906 acmm at 316°C. The faster grate speeds and increased furnace draft could have resulted in more carry-over of particulate. However, this still does not explain the low collector efficiency.

A review of the precipitator performance during sampling, as monitored by SRI, shows that high spark rates occurred. There was no evidence of back corona. According to SRI personnel who monitored the precipitator operation, the electrical characteristics were as good as could be expected for a single field precipitator. The high spark rates, however, could have decreased efficiency slightly.

After discussions with personnel from Metcalf and Eddy and Braintree's testing contractor, Air Quality Consultants, the most probable cause of the abnormal air emissions appears to be mechanical changes in boiler operation. These changes were instituted sometime between the compliance tests in November 1977 and June 1978 when corrections in plant operation were made by Metcalf and Eddy before testing. According to Metcalf and Eddy, the following malfunctions could have occurred during the MRI sampling period:*

1. Isolating damper on Boiler No. 2 not closed tightly -- The operating mechanism did not function satisfactorily and probably resulted in some air in-leakage. The damper was later replaced with one of improved design.

2. Air in-leakage at the bottom ash removal chute/quench trough interface -- The ash chutes were modified to include a sliding section for improved manual removal of the ash, but this broke the water seal at the trough. In-leakage of air would result in increased gas flow rate plus particulate reentrainment from the furnace.

3. Rotary valve at the precipitator hopper outlet -- Internal components of the rotary valves discharging ash from the ESP hoppers were removed. There could have been a back flow through the valves, thus reentraining dust in the ESP and possibly increasing emissions.

4. Ash line from economizer hopper -- A sluicing arrangement was added to the economizer hopper outlet and then modified because of plugging problems. If plugging occurred, particulate loading to the ESP could have increased.

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* Other potential problems have been more recently identified (see Section 6).

It is not definitely known if one or more of these conditions affected air emissions from the incinerator and the performance of the ESP. However, with the above problems rectified, Metcalf and Eddy reported emission levels of 0.074 gr/dscf, which is within the Massachusetts regulation for particulates.

PARTICULATE CHARACTERIZATION

After gravimetric determinations were made on the Method 5 particulate filters, the samples were further analyzed for elemental composition by SSMS and specific trace metals by AA. Results of these analyses are presented in Tables 20 and 21 and discussed below.

Trace Metals

Trace metal data in Table 20 show concentrations which parallel those found in the inlet samples but at reduced levels, with the exception of mercury. The outlet mercury concentrations were slightly greater than the inlet levels, which would seem to indicate a preferential deposition on the finer sized particulate. A good proportion of the submicron particles would be expected to pass through the precipitator (see the following discussion of particle size). However, the absolute concentration of Hg (0.014 mg/dscm) is very low and does not appear to be of concern.

The most predominant measured trace metal in the particulate emissions was lead, once again. Average lead levels were approximately 5.4 mg/dscm, compared to 11.5 mg/dscm in the inlet stream. It is difficult to discern the hazard potential of the Pb emissions since no applicable emission criterion exists.

The other trace metals assayed (Sb, As, Cd, Cu, and Fe) had relatively low concentrations. These were less than 0.5 mg/dscm. Arsenic levels were very low, averaging 0.016 mg/dscm.

Results of the SSMS analysis for elemental composition, which is shown in Table 21, indicate that the concentrations of most elements decreased slightly or remained essentially the same when compared to the inlet particulate concentrations. Several elements were slightly higher in the outlet particulate. Elements which still were present in concentrations of 1% or more in the outlet particulate included Pb and Zn. The next most prevalent elements, with concentrations greater than 1,000 μg/g, were Sb, Sn, Cu, Fe, Ti, K, P, and F.

Particle Sizing

Results of the Andersen impactor tests are presented in Table 22. The data include computed particle cutoff diameters for the individual stages and the percent weight by size collected on each stage, both including and omitting the final filter catch.

TABLE 20. ESP OUTLET PARTICULATE COMPOSITION

Constituent	Run No. 1	Run No. 2	Run No. 3	Average
Trace metals (μg/dscm)				
Sb	142	105	209	152
As	16	12	21	16
Cd	242	114	141	166
Cu	130	172	169	157
Fe	447	460	427	445
Pb	4,829	4,153	7,187	5,390
Hg	12	19	11	14
Elemental composition by SMSS	See Table 21			

TABLE 21. ELEMENTAL ANALYSIS OF ESP OUTLET, METHOD 5 PARTICULATE, BY SSMS ($\mu g/g$)[a]

Element	Run 1	Run 2	Run 2 Duplicate	Run 3	Average	Range
Uranium	0.31	0.58	3.4	0.70	1.2	0.31 - 3.4
Thorium	≤ 1.0	≤ 3.3	≤ 9.0	≤ 1.0	≤ 3.6	≤ 1.0 - ≤ 9.0
Bismuth	870	81	470	700	530	81 - 870
Lead	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Thallium	2.3	0.80	0.80	2.3	1.6	0.8 - 2.3
Mercury	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	
Gold	0.66	0.20	0.20	0.16	0.31	0.16 - 0.66
Platinum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Iridium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Osmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhenium	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Tungsten	6.6	11	15	3.1	8.9	3.1 - 15
Tantalum	0.36	0.36	0.36	0.16	0.31	0.16 - 0.36
Hafnium	< 0.79	< 0.79	< 0.80	< 0.79	< 0.79	< 0.80
Lutecium	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13
Ytterbium	< 0.66	< 0.66	< 0.66	< 0.66	< 0.66	< 0.66
Thulium	< 0.15	< 0.15	< 3.0	< 0.15	< 0.86	< 0.15 - < 3.0
Erbium	< 0.34	< 0.34	< 0.33	< 0.34	< 0.34	< 0.34
Holmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Dysprosium	< 0.15	< 0.15	< 0.14	< 0.15	< 0.15	< 0.15
Terbium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Gadolinium	< 0.38	< 0.38	< 0.37	< 0.38	< 0.38	< 0.38
Europium	< 0.15	< 0.15	< 0.14	< 0.15	< 0.15	< 0.15
Samarium	1.7	1.4	1.7	1.7	1.6	1.4 - 1.7
Neodymium	7.3	5.1	13	17	11	5.1 - 17
Praseodymium	3.5	6.1	8.1	3.5	5.3	3.5 - 8.1
Cerium	15	14	31	15	19	14 - 31
Lanthanum	11	11	11	11	11	-
Barium	270	540	270	270	340	270 - 540
Cesium	≤ 1.7	≤ 1.7	≤ 3.7	≤ 3.7	≤ 2.7	≤ 1.7 - ≤ 3.7
Iodine	87	87	75	37	72	37 - 87
Tellurium	2.0	0.72	2.0	0.72	1.4	0.72 - 2.0
Antimony	∿ 3,000	∿ 1,400	∿ 1,400	690	∿ 1,600	690 - 3,000
Tin	∿ 2,600	∿ 1,400	> 5,000	∿ 2,900	≥ 3,000	1,400 - 5,000
Indium	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	
Cadmium	730	440	440	330	480	330 - 730
Silver	50	86	110	71	79	50 - 110
Palladium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Rhodium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ruthenium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Molybdenum	51	24	21	51	37	21 - 51
Niobium	3.2	6.4	6.4	3.2	4.8	3.2 - 6.4
Zirconium	17	7.4[c]	37	15[c]	19[c]	7.4 - 37[c]

Element	Run 1	Run 2	Run 2 Duplicate	Run 3	Average	Range
Yttrium	3.7	2.2	8.0	3.1	4.2	2.2 - 8.0
Strontium	59	28	23	59	42	23 - 59
Rubidium	56	56	75	110	74	46 - 110
Bromine	∿ 1,200	350	420	900	720	350 - 1,200
Selenium	≤ 27	6.3	≤ 27	≤ 13	≤ 18	6.3 - ≤ 27
Arsenic	30	61	76	61	57	30 - 76
Germanium	7.7	3.3	7.7	15	8.4	3.3 - 15
Gallium	28	28	14	28	24	14 - 28
Zinc	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Copper	680	∿ 2,600	∿ 1,500	∿ 1,500	∿ 1,600	680 - 2,600
Nickel	IN[d]	IN[d]	IN[d]	IN[d]	NR[b]	NR[b]
Cobalt	ND[e]	11[c]	51	4.8[c]	17[c,f]	ND - 51[c,e]
Iron	∿ 2,700	∿ 4,600	∿ 3,400	∿ 3,400	∿ 3,500	2,700 - 4,600
Manganese	490	420	280	140	330	140 - 490
Chromium	260	130	260	130	200	130 - 260
Vanadium	13	17	43	21	24	13 - 43
Titanium	∿ 0.28%	∿ 0.25%	> 1%	> 1%	≥ 0.63%	0.25% - > 1%
Scandium	0.38	0.94	0.38	< 0.13	≤ 0.46	≤ 0.13 - 0.94
Calcium	> 0.5%[g]	> 1%[g]	> 1%[g]	> 1%[g]	> 0.9%[g]	> 0.5% - > 1%[g]
Potassium	> 1%	> 1%	> 0.5%	> 1%	> 0.9%	> 0.5% - > 1%
Chlorine	> 1%	> 1%	> 1%	> 1%	> 1%	> 1%
Sulphur	IN[d]	IN[d]	IN[d]	IN[d]	NR[b]	NR[b]
Phosphorus	∿ 4,400	∿ 2,400	∿ 4,400	∿ 4,400	∿ 3,900	2,400 - 4,400
Silicon	> 1%[g]	> 1%[g]	> 1%[g]	> 1%[g]	> 1%[g]	> 1%[g]
Aluminum	> 1%[g]	> 1%[g]	> 1%[g]	> 1%[g]	> 1%[g]	> 1%[g]
Magnesium	∿ 3,200[g]	∿ 4,900[g]	∿ 4,900[g]	∿ 3,200[g]	∿ 4,000[g]	3,200 - 4,900[g]
Sodium	> 1%[g]	> 0.5%[g]	> 1%[g]	> 1%[g]	> 0.9%[g]	> 0.5% - > 1%[g]
Fluorine	> 5,000	∿ 3,500	∿ 2,500	∿ 3,500	∿ 3,600	2,500 - > 5,000
Oxygen	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Nitrogen	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Carbon	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]	NR[b]
Boron	220[c]	81[c]	200[c]	510[c]	250[c]	83 - 510[c]
Beryllium	< 0.15	< 0.15	0.20	< 0.15	≤ 0.16	< 0.15 - 0.20
Lithium	210	32	92	64	100	32 - 210

a/ All values in micrograms per gram except where noted.
b/ Not reported.
c/ Values corrected for background contributions > 10% of the observed sample value.
d/ Interference by a major component spectrum.
e/ Background contribution exceeds the sample contribution.
f/ Based on three values.
g/ Values unreliable due to high background levels which exceed the range for quantitative analysis.

TABLE 22. SUMMARY OF ANDERSEN IMPACTOR RESULTS

Collection stage	50% Particle cutoff diameter (DP_{50}, μm)							Geometric mean diameter (avg.)
	Run 1	Run 2	Run 4[a]	Run 5	Run 6	Run 7	Average	
1	18.78	16.24	14.10	15.33	15.31	15.21	15.03	--
2	11.72	10.13	8.78	9.55	9.54	9.48	9.87	12.50
3	7.94	6.85	5.94	6.46	6.45	6.41	6.68	8.11
4	5.40	4.66	4.03	4.39	4.38	4.35	4.54	5.50
5	3.46	2.98	2.57	2.80	2.79	2.78	2.90	3.62
6	1.72	1.47	1.26	1.38	1.37	1.36	1.43	2.04
7	1.05	0.89	0.76	0.83	0.83	0.82	0.86	1.11
8	0.70	0.59	0.50	0.55	0.54	0.54	0.57	0.70

Collection stage	Percent by weight							Cumulative percent less than Dp (avg.)
	Run 1	Run 2	Run 4	Run 5	Run 6	Run 7	Average	
1	13.66	12.56	12.13	16.76	9.76	12.11	12.83	87.17
2	8.09	12.00	10.45	16.12	7.14	8.98	10.46	76.71
3	8.71	9.78	9.82	13.91	9.04	11.08	10.39	66.32
4	7.63	7.18	7.09	8.50	6.68	6.85	7.32	59.00
5	10.84	10.09	9.71	11.75	9.34	10.30	10.34	48.66
6	10.87	12.37	10.28	7.52	11.49	10.32	10.48	38.19
7	7.22	6.95	9.83	7.17	9.02	8.86	8.18	30.01
8	7.86	5.55	8.39	3.48	10.27	9.89	7.57	22.44
Final Filter	25.13	23.52	22.31	14.79	27.26	21.62	22.44	

Collection stage	Percent by weight omitting final filter							Cumulative percent less than Dp (avg.)
	Run 1	Run 2	Run 4	Run 5	Run 6	Run 7	Average	
1	18.24	16.42	15.61	19.67	13.42	15.45	16.47	83.53
2	10.81	15.69	13.46	18.92	9.81	11.46	13.36	70.18
3	11.64	12.79	12.64	16.32	12.42	14.14	13.33	56.95
4	10.19	9.39	9.12	9.97	9.18	8.74	9.43	47.42
5	14.47	13.20	12.49	13.78	12.85	13.14	13.32	34.09
6	14.52	16.17	13.23	8.82	15.80	13.17	13.62	20.48
7	9.64	9.08	12.66	8.42	12.41	11.30	10.59	9.90
8	10.49	7.26	10.80	4.09	14.12	12.61	9.90	

a/ Run 3 was invalidated due to mishandling of the impactor in the field.

The size distributions shown in the table were very even and consistent from run to run. The particulate distribution was not skewed toward any particular size range except for the final filter. An average of approximately 22% of the particulate weight was found on the final filter, which captured particles smaller than about 0.6 μm. Cumulative percentages indicate that slightly less than 50% of the particulate is smaller than 3 μm (mean particle size).

The outlet particle sizing results are presented graphically in Figures 8 through 10. From these figures it can be seen that the outlet distributions were much more linear and reproducible than the inlet particulate distributions. Each of the six runs produced about the same loading across any given impactor stage.

Although the mean particle size was about 3 μm, the fact that 22% of the particulate was smaller than 0.6 μm indicates a possible problem with the precipitator which could have contributed to the high outlet grain loadings. Since a fractional efficiency for the precipitator could not be calculated because of the scattered inlet data, it is difficult to assess the degree of efficiency loss beyond that normally shown by an ESP in the submicron size ranges.

GASEOUS AND VAPOROUS EMISSIONS

Carbonyls

Concentrations of carbonyls detected in the incinerator air emissions are shown in the tabulation below.

Summary of Carbonyl Emissions

Run No.	Carbonyl concentration (ppm)*
1A	1.2
1B	2.0
2A	2.6
3A	0.5
3B	0.4
Average	1.3

* Reported as formaldehyde.

Carbonyl levels were very low, averaging only 1.3 ppm. These levels were in agreement with carbonyl concentrations measured at other municipal incinerators previously shown in Table 16.

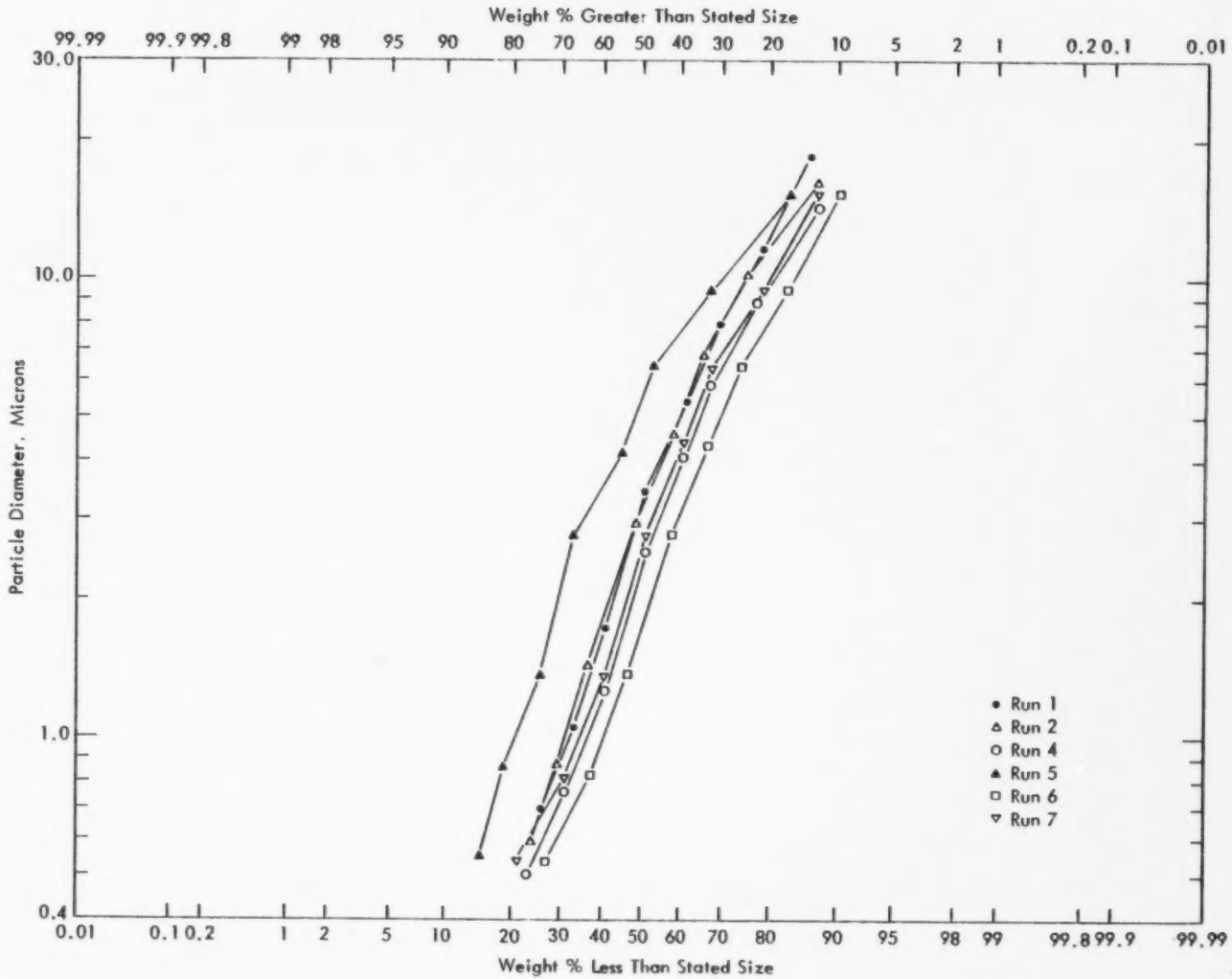

Figure 8. Particle diameter versus weight percent less/greater than stated size (outlet).

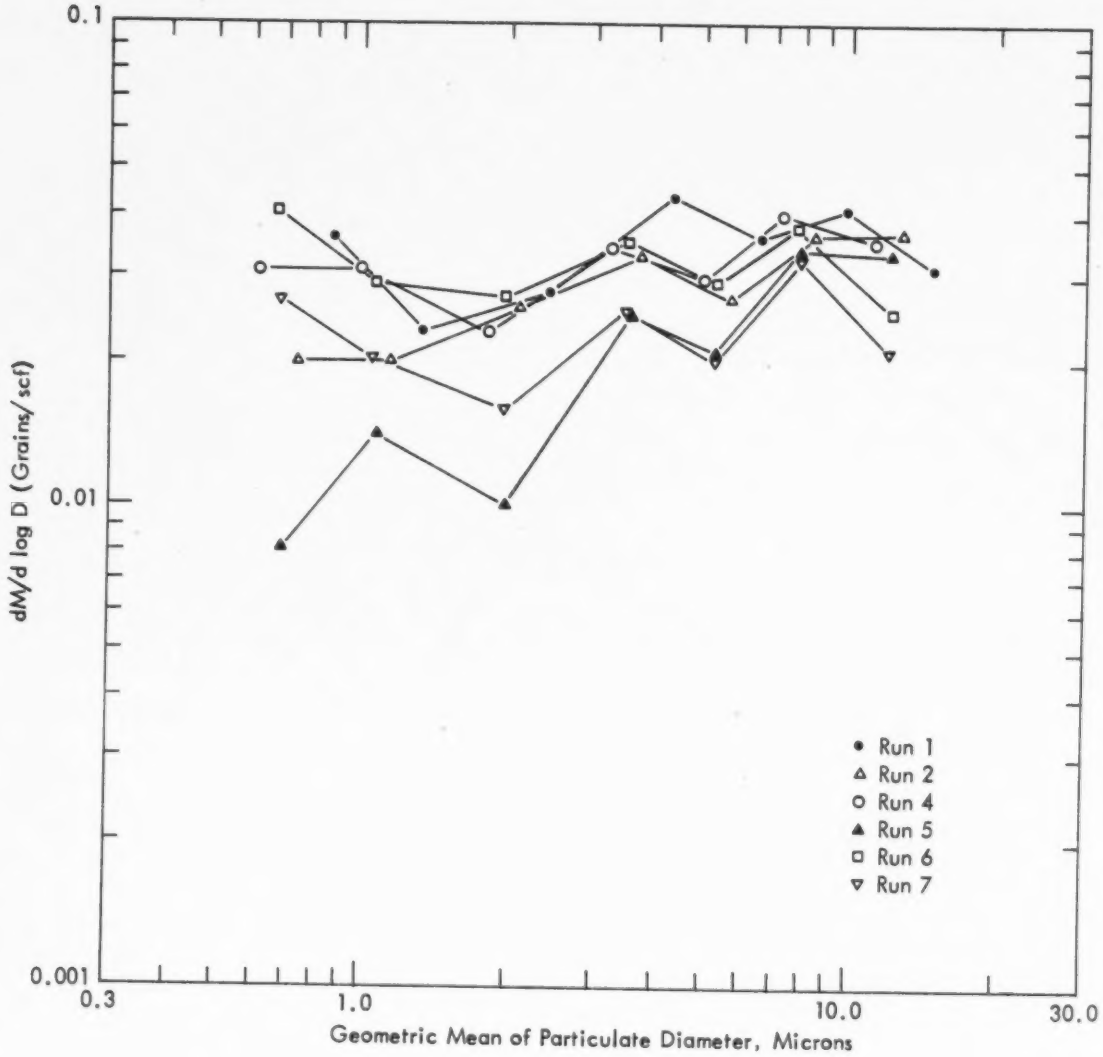

Figure 9. Differential stage loadings (outlet).

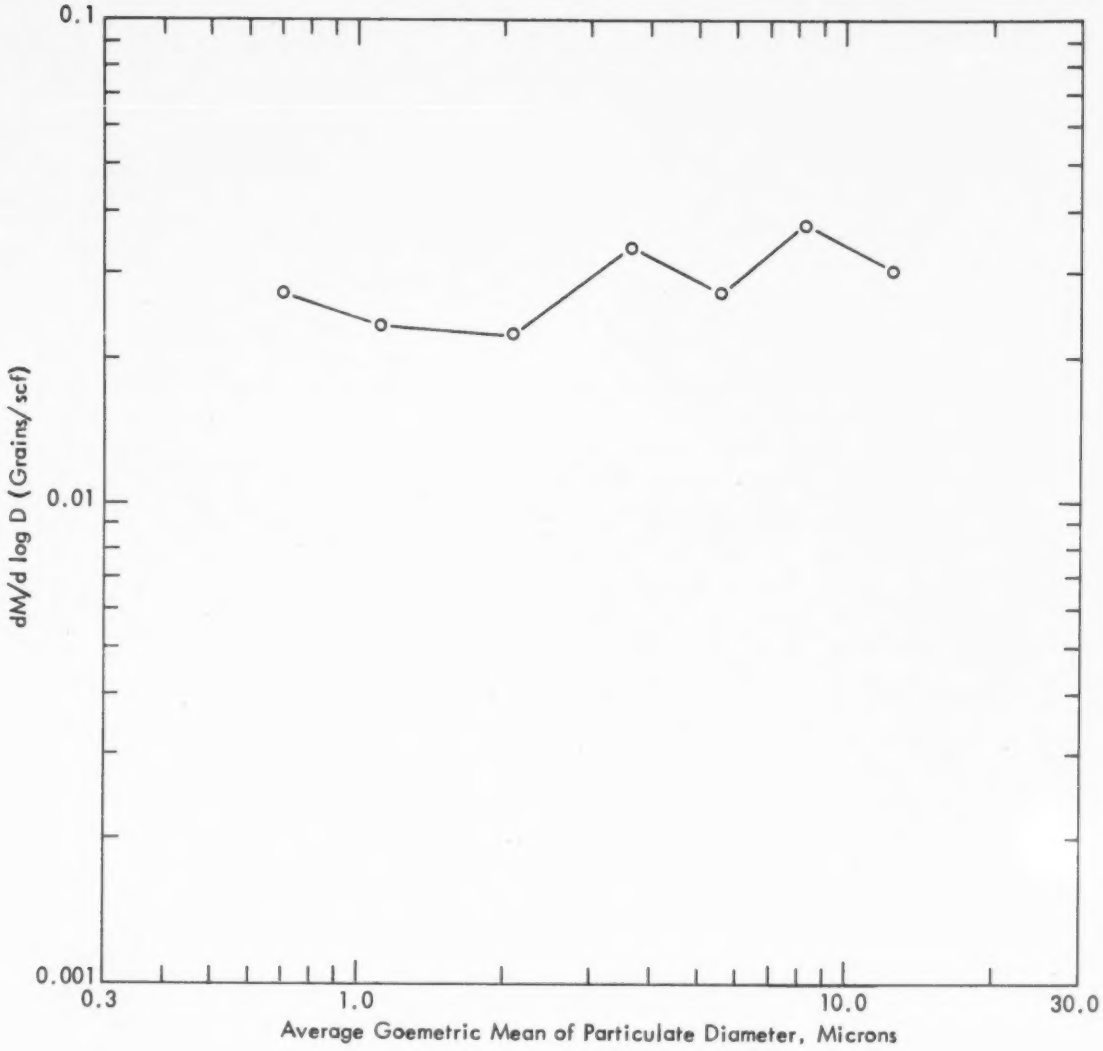

Figure 10. Average differential stage loadings (outlet).

Mercury and Anions

Table 23 summarizes results of the mercury train analysis, including assays for chlorides, fluorides, bromides, and cyanides in the KOH impinger solutions.

As seen in the table, mercury concentrations varied widely from run to run. Values ranged from 30 to 1,800 $\mu g/Nm^3$, and averaged about 560 $\mu g/Nm^3$. One possible explanation for such a wide range of vaporous mercury in the outlet gases is the variability of mercury-containing materials in the refuse. However, the refuse samples were not analyzed for mercury since it is not included in the SSMS analysis. Therefore, the Hg in refuse fluctuation cannot be substantiated, but is reasonable based on past MRI experience with refuse analysis for mercury.[5/]

No emission regulations exist limiting mercury emissions from incinerators, but the EPA does have a National Emission Standard for facilities which thermally process sludge from municipal wastewater treatment plants. This limit has been set at 3,200 g/24 hr. Even at the highest emission rate of 1,800 $\mu g/m^3$, the Braintree incinerator would emit only 1,530 g/24 hr, well below EPA's National Emission Standard for mercury.

A portion of the mercury train sample (KOH impinger) was also analyzed for four anions. The resulting concentrations of Cl^-, F^-, Br^-, and CN^- were all near or below the detection limits. The less than values shown in Table 23 indicate the detection limits for each sample.* The highest observed concentration of chlorides was 190 $\mu g/m^3$, which is about 130 ppm. This value is at the lower end of the range reported for refuse incinerators (63 to 1,260 ppm).

SASS Train (Level 1)

The EPA has developed a sampling and analytical procedure for the purpose of conducting multiphased environmental assessments. MRI employed the Level 1 approach to aid in assessing the Braintree incinerator. For the stack effluent, the high volume SASS was used to collect one sample on the 2nd day of the test program. The SASS train and its required analytical procedures are briefly explained in Appendices A and C. Results of the sample analysis are presented in Tables 24 through 26.

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* When expressed as a gas concentration, the detection limits will vary among the samples because of differences in sample gas volumes and solution volumes.

TABLE 23. MERCURY TRAIN ANALYSIS RESULTS

Run No.	Mercury ($\mu g/Nm^3$)	Chloride (mg/Nm^3)	Fluoride (mg/Nm^3)	Bromide (mg/Nm^3)	Cyanide (mg/Nm^3)
1A	< 45[a/]	< 90	< 2.1	< 6	< 2
1B	340	< 120	3.5	< 8	< 2
2A	30	< 60	< 1.5	< 4	< 1
3A	1,800	140	2.5	< 4	< 1
3B	600	190	2.1	< 5	< 1
Average	560	< 120	< 2.3	< 5	< 1

a/ A minimum of 26 $\mu g/Nm^3$ was detected in the sample but the total concentration could be as high as 45 $\mu g/Nm^3$.

TABLE 24. SASS TRAIN PARTICULATE ANALYSIS (LEVEL 1)

Constituent	Probe wash	10 µm cyclone	3 µm cyclone	1 µm cyclone	Filter
Weight (g)	0.3113	0.6164	1.2250	0.3294	1.3162
CH_2Cl_2 extract		combined		combined	
1. TCO (mg)	a/	0.017		0.042	
2. GRAV (mg)	a/	4.5		1.0	
3. IR (qualitative identification)	a/	(see Table 25)			
4. LC (7 fractions)	a/	a/		a/	
As/Hg/Sb (µg/g)					
As	a/	57	90	59	130
Hg	a/	150	14	5.6	< 4
Sb	a/	180	560	840	770
SSMS	(see Table 26)				

a/ Analysis not required under Level 1 protocol.

TABLE 25. IR SPECTRA FOR ORGANIC EXTRACT OF SASS PARTICULATE

Sample	Frequency ν (cm^{-1})	Intensity[a/]	Functional group assignment
Combined 10 µm and 3 µm particulate	2920	M	Aliphatic C-H
	2860	M	Aliphatic C-H
	1720-1740	M	Acid, ester, aldehyde, ketone
	1280	M	Aliphatic C-H
	1240	W	Aliphatic C-H
	1120-1140	W	Aliphatic C-H
	1080	W	Aliphatic C-H
	745	M	Aliphatic C-H
Combined 1 µm and filter particulate	2950	M	Aliphatic C-H
	2890	W	Aliphatic C-H

a/ M = medium transmission, 60-90% T; W = weak, > 90% T.

TABLE 26. **ELEMENTAL ANALYSIS OF SASS PARTICULATE BY SSMS (μg/g)**

Element	10 μm	3 μm	1 μm	Filter	Element	10 μm	3 μm	1 μm	Filter
Uranium	1.6	0.31	0.36	0.29	Ruthenium	< 1.0	< 0.10	< 0.10	< 0.10
Thorium	≤ 5.0	≤ 3.6	≤ 3.0	≤ 0.059	Molybdenum	62	900	73	12
Bismuth	440	~ 1,200	580	230	Niobium	7.6	6.4	4.9	1.2
Lead	~ 3,600	> 10,000	10,000	9,900	Zirconium	7.0	20	20	1.7[b]
Thallium	≤ 1.9	1.1	3.3	0.29	Yttrium	7.3	35	18	2.8
Mercury	NR[a]	NR	NR	NR	Strontium	500	280	140	ND[c]
Gold	< 0.10	< 0.10	1.2	0.19	Rubidium	200	200	410	150
Platinum	< 0.10	< 0.10	< 0.10	< 0.10	Bromine	~ 1,600	~ 4,800	~ 3,300	> 5,000
Iridium	< 0.10	< 0.10	< 0.10	< 0.10	Selenium	≤ 41	≤ 52	22	3.0
Osmium	< 0.10	< 0.10	< 0.10	< 0.10	Arsenic	210	610	1,200	23
Rhenium	NR	NR	NR	NR	Germanium	37	370	36	3.3
Tungsten	5.0	15	15	1.8	Gallium	45	81	1.0	14
Tantalum	0.60	1.4	1.8	0.26	Zinc	> 10,000	> 10,000	> 10,000	> 10,000
Hafnium	3.7	< 1.1	< 1.1	< 0.76	Copper	950	~ 3,300	~ 3,300	680
Lutecium	1.9	< 0.10	< 0.13	< 0.13	Nickel	360	130	230	INT[d]
Ytterbium	2.1	< 0.53	< 0.55	< 0.66	Cobalt	36	810	19	ND[c]
Thulium	0.29	< 0.22	< 0.22	< 0.15	Iron	> 5,000	> 10,000	> 10,000	2,200
Erbium	< 0.71	< 0.67	< 0.67	< 0.34	Manganese	~ 1,300	900	~ 1,200	2,500
Holmium	0.16	≤ 0.21	< 0.10	< 0.10	Chromium	830	820	760	46
Dysprosium	0.63	≤ 0.39	< 0.13	< 0.15	Vanadium	60	43	24	8.4[b]
Terbium	0.54	< 9.0	< 0.10	< 0.10	Titanium	> 10,000	> 5,000	> 5,000	1,300
Gadolinium	312	1.2	< 0.42	< 0.38	Scandium	5.0	14	< 0.27	< 0.13
Europium	0.94	≤ 19	< 0.19	< 0.15	Calcium	> 10,000	> 10,000	> 10,000	> 4,500[e]
Samarium	3.6	4.3	≤ 1.2	1.2	Potassium	> 10,000	> 10,000	> 10,000	> 10,000
Neodymium	10	19	11	2.6	Chlorine	> 10,000	> 10,000	> 10,000	> 10,000
Praseodymium	14	14	5.8	1.2	Sulfur	> 10,000	> 10,000	> 10,000	INT[d]
Cerium	76	15	17	4.9	Phosphorus	> 5,000	> 10,000	> 10,000	2,400
Lanthanum	31	25	16	2.0	Silicon	> 10,000	> 10,000	> 10,000	> 9,000[e]
Barium	~ 1,600	500	1,000	120	Aluminum	> 10,000	> 10,000	> 10,000	> 9,000[e]
Cesium	< 4.1	≤ 9.0	≤ 20	6.4	Magnesium	> 10,000	> 10,000	> 5,000	≤ 720[e]
Iodine	340	39	< 0.39	1.3	Sodium	< 5,000	> 10,000	> 10,000	> 9,000[e]
Tellurium	0.18	≤ 0.45	1.3	0.29	Fluorine	> 10,000	> 10,000	~ 3,000	650
Antimony	300	~ 3,900	1,800	690	Oxygen	NR	NR	NR	NR
Tin	~ 1,600	> 10,000	> 5,000	2,900	Nitrogen	NR	NR	NR	NR
Indium	NR	NR	NR	NR	Carbon	NR	NR	NR	NR
Cadmium	340	440	450	1,200	Boron	58	630	91	24[b]
Silver	110	300	160	40	Beryllium	0.41	< 0.48	0.33	< 0.15
Palladium	< 0.10	< 0.10	< 0.10	< 0.10	Lithium	86	130	150	NR
Rhodium	< 0.10	< 0.10	< 0.10	< 0.10					

a/ NR = not run.

b/ Background corrected value.

c/ Background levels exceeded sample levels.

d/ Interference by a major component spectrum.

e/ Corrected values of low reliability--background and/or sample concentration exceeded range of quantitative analysis.

Particulate Analysis--

The total particulate concentration measured by the SASS train was shown previously in Table 17. The value of 0.138 g/dscm was lower than the concentration determined from the Method 5 particulate test, 0.191 g/dscm, but the discrepancy is, most likely, due to the fact that the SASS sample is drawn from a single point in the stack, whereas the Method 5 procedure traverses the entire cross-sectional area. Results for the individual components of the SASS particulate sample are shown in Table 24.

An interesting observation is that a large portion of the SASS particulate was captured on the filter (~ 38%), which indicates a large proportion of submicron particulate. Another 35% of the particulate weight was found in the 3 μm cyclone catch. These values vary slightly, but are in general agreement with the Andersen impactor results summarized in Table 22.

Additional analyses of the SASS particulate, as prescribed under the Level 1 procedures, included a methylene chloride extraction for quantitative and qualitative analysis of organic components, assays for arsenic, antimony, and mercury, and elemental composition analysis by SSMS. These results are discussed next.

Once the organic extraction is performed, the Level 1 procedure specifies determination of total chromatographable organics (TCO), gravimetric (GRAV) residue, and infrared (IR) qualitative identification, with additional liquid chromatographic (LC) fractionation if the TCO plus GRAV values equal 15 mg or more. These results are shown in Tables 24 and 25. Interpretation of these data is difficult and one method of interpretation (SAM-1A) is presented in a later section of this report.

Results of the assays for As, Sb, and Hg are also presented in Table 24. As and Hg values were relatively low, but concentrations of Sb were much higher. The Sb concentrations also appeared to increase in the smaller size fractions. Mercury, in contrast, showed lower concentrations with decreasing particle size. No trend could be discerned from the As results.

Elemental composition of the SASS particulate, as determined by SSMS analysis, is presented in Table 26. Results are shown for each of the four particulate fractions.

It is interesting to note that the concentrations of As and Sb as determined by SSMS are much higher than those resulting from the AA analysis just discussed. Though the AA method is the more accurate of the two, such a large discrepancy may be the result of differences in sample preparation techniques for AA and SSMS (see Appendix A). Other noteworthy elements found in high concentrations included Bi, Pb, Ba, Sn, Cd, Zn, Cr, and Ti. Many of the common elements (Ca, K, S, Al, etc.) were detected at levels beyond the upper limit of the SSMS instrumental capability (> 1%).

XAD-2 Resin and Organic Module Rinse--

The organic module of the SASS train serves to adsorb gaseous organic pollutants from the sample stream using an adsorbant known as XAD-2 resin (see Figure 3-2, p. 15). Both the resin itself and the rinse of the internal surfaces of the organic module are collected for analysis. Results of the analyses of the XAD-2 resin and organic module rinse are summarized in Tables 27 through 31.

These two fractions of the organic trap portion of the SASS train were also analyzed for PCB compounds. No detectable levels of PCBs were seen in the GC screening of the organic module rinse, but a derivatized aliquot of the XAD-2 resin extract showed a total PCB concentration of 4 $\mu g/m^3$ (as DCB). Structural confirmation by GC/MS techniques indicated the presence of trichlorobiphenyl and possibly tetrachlorobiphenyl compounds in the extract.

The organic fractions were also assayed for the PAH compounds shown in Table 27. The organic module rinse was not found to contain any detectable levels of the 14 PAH compounds. However, analysis of the XAD-2 resin extract revealed the presence of six of the compounds. The more hazardous PAH compounds (based on their low MATE values) such as benzo[a]pyrene (BaP) and 1,2,5,6-dibenzanthracene, were not detectable. The highest concentration noted was for phenathrene with 4 $\mu g/m^3$, a relatively small amount.

Level 1 of the XAD-2 resin extract and organic module rinse requires determination of TCO, GRAV, and IR qualitative identification, with subsequent LC fractionation and GRAV/TCO determinations for each fraction. These results are shown in Table 27. The batch inlet LRMS analyses were performed on samples having high TCO content (> 2 mg). The two samples which fulfilled this requirement were XAD-2 resin extract and aqueous condensate extract. The resulting spectra primarily consisted of methylene chloride, the extraction solvent in both cases. Additional ions of significant intensity to permit data interpretation were not observed.

The direct inlet LRMS analysis was performed on four LC fraction samples, LC5 and LC6 of XAD-2 resin sample and LC5 and LC6 of the corresponding XAD-2 blank. Due to the complexity of the sample mixture, these analyses yielded little useful information with which to identify specific compounds or compound types present. Further structural characterization may have been possible by high resolution MS or GC/MS methods which exceed the Level 1 analytical requirements.

In an attempt to derive some information from the direct inlet LRMS, the data were assembled in an alternate manner. A matrix of mass versus intensity was constructed for selected sample spectra after subtraction of the blank signals. The matrix was used to identify homologous series which might be present in the sample. After a series is identified, a map was consulted to identify compound classes which could yield such a series.

TABLE 27. SASS TRAIN XAD-2 RESIN AND ORGANIC MODULE RINSE ANALYSES (LEVEL 1)

Constituent	Organic module rinse	XAD-2 resin extract
PCB as DCB ($\mu g/m^3$) a/	b/	4
PAH ($\mu g/m^3$) a/		
1. Acenaphthylene	b/	1
2. Fluorene	b/	1
3. Phenanthrene	b/	4
4. Anthracene	b/	2
5. Fluoranthrene	b/	2
6. Pyrene	b/	1
7. 1,2-Benzanthracene	b/	b/
8. Chrysene	b/	b/
9. Benzo[e]pyrene	b/	b/
10. Benzo[a]pyrene	b/	b/
11. Perylene	b/	b/
12. Indeno(1,2,3-C,D)pyrene	b/	b/
13. 1,12-Benzoperylene	b/	b/
14. 1,2,5,6-Dibenzanthracene	b/	b/
TCO ($\mu g/m^3$)	3.0	355
GRAV ($\mu g/m^3$)	145	2,300
IR (qualitative identification)	See Table 25	
LC - 7 fractions		
1. GRAV ($\mu g/m^3$)	c/	
LC1		100
LC2		51
LC3		31
LC4		51
LC5		NR
LC6		690
LC7		200

(continued)

TABLE 27. (continued)

Constituent	Organic module rinse	XAD-2 resin extract
2. TCO ($\mu g/m^3$)	c/	
LC1		0.83
LC2		72
LC3		90
LC4		72
LC5		98
LC6		170
LC7		16
3. IR	See Table 29	
4. LRMS	See Table 30	
As/Sb/Hg ($\mu g/m^3$)		
As	c/	18
Sb	c/	53
Hg	c/	19
Elemental composition (SSMS)	See Table 31	

a/ Additional analyses selected by MRI.

b/ Below level of instrumental detection.

c/ Not required by Level 1 protocol.

TABLE 28. IR SPECTRAL ANALYSIS OF SASS ORGANIC MODULE RINSE AND XAD-2 RESIN EXTRACT[a/]

Sample	ν (cm^{-1})	Intensity[b/]	Assignment(s)
Organic Module Rinse	2940	M	Aliphatic C-H
	2870	W	Aliphatic C-H
	1720-1780	W	Ester, acid, aldehyde, ketone
XAD-2 Resin Extract	2970	W	Aliphatic C-H
	2940	W	
	2870	M	
	2320	W	Unassigned weak bands
	1730	M	Carbonyl, esters, acids, aldehydes
	1630-1640	W	Unassigned weak bands
	1595	W	
	1575	W	
	1550	W	
	1445	M	Acids, alkanes, alkenes
	1425	M	Aliphatic aldehydes, acids
	1370	W	Acids, aldehydes
	1335	W	Acids, aldehydes
	1260	S	Acids, esters, ketones
	1175	W	Ketones
	1120	W	Aliphatic ethers, ketones
	1070	W	Aldehydes, aromatics, esters
	1025	W	Aldehydes, ethers
	840-850	W	Acids, aldehydes
	730-745	S	Amines, aromatics

a/ Based on data from the concentrated sample.

b/ S = strong, 60% transmission; M = medium, 60-90% T; W = weak, 90% T.

TABLE 29. IR SPECTRAL ANALYSIS OF XAD-2 RESIN EXTRACT LC FRACTIONATION

LC fraction	ν (cm^{-1})	Intensity[b]	Assignment(s)
LC1	2940	M	Aliphatic C-H
	2870	M	Aliphatic C-H
LC2	2940	M	Aliphatic C-H
	2870	W	Aliphatic C-H
LC3	a/	a/	a/
LC4	2920	W	Aliphatic C-H
	2850	W	Aliphatic C-H
LC5	2940	W	Aliphatic C-H
	2870	W	Aliphatic C-H
	1720-1730	W	Acids, aldehydes, esters, ketones
	1020-1080	W	Aromatic or aliphatic
	750-770	W	Aromatic
LC6[c]	3200-3500	M	O-H and N-H stretch
	2970	M	
	2940	M	Aliphatic C-H
	2880	M	
	1700-1720	M	Acids, aldehydes, esters, ketones
	1590	W	Unassigned weak
	1550	M	Aromatics
	1450	W	Acids, alkanes, alkenes
	1330-1340	W	Acids, alkanes, aldehydes
	1275	M	Acids, ethers, ketones
	1070	W	Aldehydes, aromatics, esters
	850-870	W	Acids, aldehydes,
	740	W	Aromatics
LC7	2980	W	Aliphatic C-H
	2940	W	Aliphatic C-H
	2870	W	Aliphatic C-H
	1660-1730	W	Acids, aldehydes, esters, ketones
	1540-1610	W	Acids, amides, aromatics
	1070-1080	W	Aldehydes, aromatics, esters

a/ No major absorbance peaks.

b/ M = medium, 80-95% transmission; W = weak, 95% T.

c/ Based on data from the concentrated sample.

TABLE 30. POSSIBLE COMPOUND CLASS IDENTIFICATIONS FROM LRMS OF SELECTED LC FRACTIONS

Note: Only LC5 and LC6 fractions of the XAD-2 resin extract sample were analyzed by direct inlet MS. All other fractions were rejected due to insufficient quantities of TCO and gravimetric materials (< 0.5 mg/μm^3)

Fraction 5

Temperature:	40°C	150°C	460°C
Categories:	Aldoximes	Acetanilides	Aldoximes
	Aliphatic alcohols	Alkylbenzthiophenes	Aliphatic alcohols
	Aliphatic carboxylic acids	Aromatic alcohols	Aliphatic carboxylic acids
	Aliphatic esters	Aromatic carboxylic acids	Aliphatic esters
	Aliphatic ethers	Aromatic nitro compounds	Aliphatic ethers
	Cycloalkylthiaalkanes	Benzoates	Cycloalkythiaalkanes
	1,3-Dioxolanes	Benzodithiophenes	1,3-Dioxolanes
	Ethoxides	Benzyl esters	Ethoxides
	Formates	Benzylbenzoates	Formates
	Isoquinolines	Benzylthiazoles	Isoquinolines
	Isothiocyanates	Indoles	Isothiocyanates
	Ketoximes	Oxindoles	Ketoximes
	Quinolines	Phenyl tolyl esters	Quinolines
	Thiocycloalkanes	Phanylalkylaziridines	Thiocycloalkanes
	Thiocyanates	Tetrahydroquinolines	Thiocyanates
		Thioethers	
		Toluates	

(continued)

TABLE 30. (continued)

Fraction 6

Temperature:	40°C	150°C	460°C
Categories:	Anilines	Aldoximes	Acetanilides
	Alkyl phenols	Aliphatic alcohols	Aromatic alcohols
	Aromatic acids	Aliphatic carboxylic acids	Aromatic carboxylic acids
	Aromatic alcohols	Aliphatic esters	Aromatic nitro compounds
	Aromatic amines	Amines	Benzoates
	Aromatic isothiocyanates	Cycloalkylthiaalkanes	Benzodithiophene
	Benzothiazoles	1,3-Dioxolanes	Benzyl ester
	Cinnamates	Ethoxides	Benzylbenzoates
	Diphenyl sulfones	Formates	Benzylthiazoles
	Nitro phenols	Isoquinolines	Oxindoles
	Pyridines	Isothiocyanates	Phenyl tolyl esters
	Salicylates	Ketoximes	Phenylalkylaziridine
	Vinyl furans	Quinolines	Tetrachydoquinolines
		Thiacycloalkanes	Thioethers
		Thiocyanates	Toluates

TABLE 31. ELEMENTAL COMPOSITION OF SASS XAD-2 RESIN[a/]

Element	μg/g of resin	μg/m³	Element	μg/g of resin	μg/m³
Uranium	< 0.10	< 0.62	Ruthenium	< 0.10	< 0.62
Thorium	< 0.25[c/]	< 1.5[c/]	Molybdenum	< 0.50[c/]	< 2.9[c/]
Bismuth	< 0.10	< 0.62	Niobium	< 0.10	< 0.62
Lead	< 0.56[c/]	< 3.3[c/]	Zirconium	< 0.56[c/]	< 3.3[c/]
Thallium	< 0.19	< 1.1	Yttrium	< 0.10	< 0.62
Mercury	NR	NR	Strontium	0.09[b/]	0.54[b/]
Gold	0.10	0.62	Rubidium	< 0.10	< 0.62
Platinum	NR	NR	Bromine	0.15[b/]	0.87[b/]
Iridium	NR	NR	Selenium	< 0.10	< 0.62
Osmium	< 0.16	< 0.94	Arsenic	< 0.10[c/]	< 0.62[c/]
Rhenium	NR	NR	Germanium	< 0.10	< 0.62
Tungsten	< 0.12	< 0.69	Gallium	< 0.10	< 0.62
Tantalum	< 0.10	< 0.62	Zinc	< 8.6[c/]	< 51[c/]
Hafnium	< 0.22	< 1.3	Copper	< 8.6[c/]	< 51[c/]
Lutecium	< 0.10	< 0.62	Nickel	< 6.8[c/]	< 40[c/]
Ytterbium	< 0.10	< 0.62	Cobalt	< 0.21[c/]	< 1.2[c/]
Thulium	< 0.10	< 0.62	Iron	< 25[c/]	< 150[c/]
Erbium	< 0.13	< 0.76	Manganese	< 1.9[c/]	< 11[c/]
Holmium	< 0.10	< 0.62	Chromium	< 2.3[c/]	< 14[c/]
Dysprosium	< 0.10	< 0.62	Vanadium	< 0.10	< 0.62
Terbium	< 0.10	< 0.62	Titanium	6.0[b/]	35[b/]
Gadolinium	< 0.10[c/]	< 0.62[c/]	Scandium	< 0.10	< 0.62
Europium	< 0.10	< 0.62	Calcium	8.0	47
Samarium	< 0.22	< 1.3	Potassium	< 17[c/]	< 101[c/]
Neodymium	< 0.15	< 0.87	Chlorine	10[b/]	58[b/]
Praseodynium	< 0.10	< 0.62	Sulfur	68[b/]	400[b/]
Cerium	< 0.10	< 0.62	Phosphorus	< 8.6[c/]	< 51
Lanthanum	< 0.10	< 0.62	Silicon	NR	NR
Barium	< 0.25[c/]	< 1.5[c/]	Aluminum	< 19[c/]	< 112[c/]
Gerium	< 0.10	< 0.62	Magnesium	< 12[c/]	< 69[c/]
Iodine	0.10	0.62	Sodium	< 17	< 101
Tellurium	< 0.10[c/]	< 0.62[c/]	Fluorine	< 0.80[c/]	< 4.7[c/]
Antimony	< 0.10	< 0.62	Oxygen	NR	NR
Tin	< 0.10	< 0.62	Nitrogen	NR	NR
Indium	NR	NR	Carbon	NR	NR
Cadmium	< 0.10	< 0.62	Boron	< 8.2[c/]	< 43[c/]
Silver	18	105	Beryllium	< 0.10	< 0.62
Palladium	< 0.10	< 0.62	Lithium	< 0.10	< 0.62
Rhodium	< 0.10	< 0.62			

a/ Values are inconclusive due to large background levels.

b/ Background corrected value.

c/ Background levels exceeded sample levels.

NR = Not run.

The LC fraction being analyzed was then considered with respect to classes of compounds which might elute in the solvent system used. Those classes identified by map consultation which would not elute were eliminated from consideration. The remaining classes are those possibly present in the samples. Listings of the possible compounds classes at three different temperatures during the direct inlet temperature program for each sample are shown in Table 30. It must be noted that the use of this technique assumes the presence of homologous series of particular compound classes which may in fact not be the case. Data interpretation is further hampered by the incomplete listing of compound types eluted in specific LC fractions. Interpretation of these data involves use of the SAM-1A procedure and is discussed in a later section of this report.

The XAD-2 resin was also analyzed for As, Sb, and Hg under the Level 1 analytical protocol. As shown in Table 27, the concentrations of both arsenic and antimony were below the limit of detection. The Hg value reported was also very low.

Finally, a SSMS analysis of the XAD-2 resin was performed to determine its elemental composition. Results are tabulated in Table 31. The concentrations of most elements were below instrumental detection limits. High background levels for several elements were also found in the XAD-2 resin blank. One surprising concentration was that of silver at 105 $\mu g/m^3$. Other elements which were quantitatively detected by SSMS included Sr, Br, Ti, Ca, Cl, and S.

Aqueous Condensate and Impinger Solutions--

The aqueous condensate from the SASS condenser module and the three impinger solutions were to be analyzed as prescribed by the Level 1 protocol, with additional analyses contemplated by MRI. However, most of the analyses of the impinger catches were not carried out because of quantities less than those required for the Level 1 procedures. This is indicated in Table 32 along with results for the completed analyses.

No PCBs were detectable in the aqueous condensate at the instrumental detection limit. The impinger solutions were not assayed for PCBs.

As shown in Table 32, PAH analyses were carried out on the aqueous condensate from the SASS run. Only five of the 14 compounds assayed were presented in detectable quantities. The most prominent PAH compound was fluoranthene, with a concentration of only 4 $\mu g/m^3$.

The aqueous condensate underwent an organic extraction with methylene chloride and subsequent analysis for TCO and GRAV (Table 32). The IR spectral analysis, shown in Table 33 indicates a variety of functional group assignments. LC fractionation of the condensate extract resulted in quantitative values for only fractions 3, 6, and 7 (both TCO and GRAV). Extensive functional group assignments were possible only for the IR spectra from fractions LC6 and LC7. The IR spectra for LC fractions 1 through 5 consisted of weak, featureless absorptions (see Table 34).

TABLE 32. ANALYSIS OF SASS AQUEOUS CONDENSATE AND IMPINGER SOLUTIONS (Level 1)

	Condensor water	Impinger 1	Impinger 2	Impinger 3
PCB as DCB ($\mu g/m^3$)a/	NDb/	NAc/	NA	NA
PAH ($\mu g/m^3$)a/		NA	NA	NA
1. Acenaphthylene	ND			
2. Fluorene	0.4			
3. Phenanthrene	3			
4. Anthracene	ND			
5. Fluoranthrene	4			
6. Pyrene	3			
7. 1,2-Benzanthracene	0.2			
8. Chrysene	ND			
9. Benzo[e]pyrene	ND			
10. Benzo[a]pyrene	ND			
11. Perylene	ND			
12. Indeno(1,2,3-C,D)pyrene	ND			
13. 1,2-Benzoperylene	ND			
14. 1,2,5,6-Dibenzanthracene	ND			
TCO ($\mu g/m^3$)	90.5	NA	NA	NA
GRAV ($\mu g/m^3$)	1,104	NA	NA	NA
IR (qualitative identification)	See Table 4-30			
LC (seven fractions)				
1. GRAV ($\mu g/m^3$)				
LC1	ND			
LC2	ND			
LC3	109			
LC4	ND			
LC5	ND			
LC6	243			
LC7	134			
2. TCO ($\mu g/m^3$)				
LC1	ND			
LC2	ND			
LC3	14			
LC4	ND			
LC5	ND			
LC6	72			
LC7	40			
3. IR/LRMS (qualitative identification)		See Table 4-31		
As/Sb/Hg ($\mu g/m^3$)				
As	1.5	4.7	< 0.54	< 0.40
Sb	< 0.54	1.4	< 0.65	< 0.47
Hg	14	33	11	11
Elemental composition by SSMS	See Table 4-32			

a/ Additional analyses selected by MRI.

b/ Not detected at instrument detection level.

c/ Not analyzed under Level 1 protocol or MRI procedures.

TABLE 33. IR SPECTRAL ANALYSIS OF SASS AQUEOUS CONDENSATE EXTRACT[a]

ν (cm^{-1})	Intensity[b]	Assignment(s)
2960	M	Aliphatic C-H
2930	M	
2860-2880	W	
1730	S	Acids, aldehydes, esters, ketones
1570-1600	W	Unassigned weak bands
1425	M	Aliphatic aldehydes, acids
1370	M	Aliphatic aldehydes, acids
1325	M	Acids, aldehydes
1235	S	Ketones, ethers, acids
1125	M	Ketones, aliphatic ethers
1080	M	Aldehydes, esters, aromatics
1020	M	Aldehydes, ethers
970	M	Acids, aldehydes
935-950	M	Acids, aldehydes
830-850	W	Acids, aldehydes
745	W	Aromatics

a/ Based on data from the concentrated sample.

b/ S = strong, < 60% transmission
M = medium, 60-90% T
W = weak, > 90% T.

TABLE 34. IR SPECTRAL ANALYSIS OF SASS AQUEOUS CONDENSATE EXTRACT LC FRACTIONATION

LC Fraction	ν (cm^{-1})	Intensity[a]	Assignment(s)
1	2950	M	Aliphatic C-H
	2890	M	Aliphatic C-H
2	2970	W	Aliphatic C-H
	2900	W	Aliphatic C-H
3	2920	M	Aliphatic C-H
	2850	W	Aliphatic C-H
	800-825	W	Unassigned weak bands
	740-760	W	Unassigned weak bands
4	2940	W	Aliphatic C-H
	2970	W	Aliphatic C-H
5	2950	W	Aliphatic C-H
	2880	W	Aliphatic C-H
6	2980	S	Aliphatic C-H
	2950	S	
	2890	M	
	1725	S	Acid, aldehyde, ester, ketone
	1590	W	Unassigned weak bands
	1570	W	
	1280	M	Acid, ether, ketone
	1200	M	Esters, aromatic ethers and ketones
	1125	M	Ketones, aliphatic ethers
	1075	M	Aromatics, aldehydes, esters
	1020-1040	W	Aldehydes, ethers
	960	W	Aldehydes, acids
	940	W	Aldehydes, acids
	745	M	Aromatics, amines
7	2940-2970	M	Aliphatic C-H
	2860-2880	M	
	1735	S	Acids, aldehydes, esters, ketones
	1600	W	Unassigned weak bands
	1580	W	
	1290	M	Acids, ethers, ketones
	1210	M	Esters, aromatic ethers and ketones
	1130	M	Ketones, aliphatic esters
	1080	M	Aldehydes, aromatics, esters
	1025-1040	W	Aldehydes, aromatics, esters
	940-970	W	Acids, aldehydes
	750	W	Amines, aromatics

a/ S = strong, < 70% transmission
M = medium, 70-90% T
W = weak, > 90% T

Elemental composition data from SSMS analysis of the aqueous condensate and first impinger are tabulated in Table 35. Among the more prominent elements in the condensate were Pb, I, Mo, Br, Zn, Cu, Ni, Fe, Mn, Cr, S, Si, and F. Nearly all of the remaining elements were at or below the limit detection. The elements contained in the impinger catch in concentrations > 10 $\mu g/m^3$ included Pb, Mo, Zn, Cu, Co, Ni, Fe, Mn, Cr, V, Ti, Ca, K, S, Si, Al, Mg, and Na.

TABLE 35. ELEMENTAL COMPOSITION OF SASS AQUEOUS CONDENSATE AND FIRST IMPINGER ($\mu g/m^3$)

Element	Aqueous condensate	Impinger	Element	Aqueous condensate	Impinger
Uranium	< 0.12	< 0.21	Ruthenium	0.02	0.05
Thorium	< 0.12	< 0.26	Molybdenum	80	87
Bismuth	4.0	4.3	Niobium	1.4	6.2
Lead	35	87	Zirconium	0.22	0.16
Thallium	< 0.24	0.65	Yttrium	0.04	0.21
Mercury	NR	NR	Strontium	0.40	0.21
Gold	< 0.02	< 0.05	Rubidium	0.04	0.31
Platinum	< 0.02	< 0.05	Bromine	300	3.4
Iridium	< 0.02	< 0.05	Selenium	0.10	0.76
Osmium	< 0.02	< 0.05	Arsenic	3.2	1.8
Rhenium	NR	NR	Germanium	0.26	0.05
Tungsten	0.40	1.2	Gallium	< 0.02	< 0.05
Tantalum	0.16	0.36	Zinc	62	220
Hafnium	< 0.47	< 1.0	Copper	54	360
Lutecium	< 0.06	< 0.16	Nickel	160	250
Ytterbium	< 0.24	< 0.72	Cobalt	8.7	22
Thulium	< 0.10	< 0.16	Iron	3,500	6,200
Erbium	< 0.31	< 0.65	Manganese	40	43
Holmium	< 0.04	< 0.05	Chromium	360	1,600
Dysprosium	< 0.06	< 0.21	Vanadium	1.1	43
Terbium	< 0.04	< 0.05	Titanium	1.9	14
Gadolinium	< 0.20	< 0.40	Scandium	< 0.12	0.21
Europium	< 0.08	< 0.26	Calcium	13	110
Samarium	< 0.27	< 0.73	Potassium	22	150
Neodymium	< 0.24	< 0.40	Chlorine	NR	11
Praseodymium	< 4.7	< 0.21	Sulfur	340	4,600
Cerium	< 0.08	< 0.26	Phosphorus	16	62
Lanthanum	< 3.6	< 0.21	Silicon	47	100
Barium	2.2	1.0	Aluminum	5.8	31
Cesium	< 0.02	< 0.05	Magnesium	< 1.9	20
Iodine	36	< 0.36	Sodium	NR	400
Tellurium	< 0.04	< 0.05	Fluorine	240	3.0
Antimony	< 0.10	0.26	Oxygen	NR	NR
Tin	0.90	1.4	Nitrogen	NR	NR
Indium	NR	NR	Carbon	NR	NR
Camium	< 0.10	0.26	Boron	NR	NR
Silver	0.20	7.6	Beryllium	< 0.16	< 0.16
Palladium	< 0.02	< 0.05	Lithium	< 0.04	0.87
Rhodium	< 0.02	< 0.05			

NR = Not run.

SECTION 5

ENVIRONMENTAL ASSESSMENT OF BRAINTREE DATA BASED ON EPA'S SAM 1-A

APPROACH

The environmental assessment data obtained from MRI's study of the Braintree municipal incinerator provide a great deal of quantitative and semi-quantitative information about pollutants in the air, water, and solid waste streams resulting from thermal processing of refuse. To ascertain the significance of these data and thereby determine the need for control of any particular pollutants that may be of concern, a comparative set of emission criteria is needed. Although some emission level goals have been established in the form of EPA's New Source Performance Standards and Effluent Guidelines and Standards, these regulations are source-specific and extrapolation to other types of processes may not be valid. There are also many pollutant species, such as many forms of hydrocarbons, certain pesticides, trace metals, etc., for which emission limitations have never been promulgated.

Therefore, a standardized data evaluation methodology recently developed by EPA's Industrial Environmental Research Laboratory - Research Triangle Park/ Energy Assessment and Control Division (IERL-RTP/EACD) was employed to interpret the Braintree test results. The IERL-RTP/EACD evaluation scheme consists of using a data calculation procedure known as SAM-1A to compare effluent stream contaminant levels to Multimedia Environmental Goals (MEGs), which are also being developed by IERL-RTP.[6/] MEGs are guideline limitations for contaminants that are judged to be: (a) appropriate for preventing certain negative effects in the surrounding populations or ecosystems (ambient air, water, or land); or (b) representative of the control limits achievable through application of the best available technology. These emission level goals are approximated using: (a) ambient concentration goals which are based on hazards posed to public health and welfare as a result of long-term or continuous exposure to emissions; (b) natural background levels which can be used as ultimate goals for the elimination of discharges; and (c) hazards to human health or to ecology from short-term exposure to emissions. Those MEGs derived from short-term exposure data are Minimum Acute Toxicity Effluents (MATE) values and are intended to serve both as relative hazard indicators and very approximate emission guidelines. Pollutants emitted at levels lower than these guidelines are

not expected to evoke significant harmful or irreversible responses from exposures of less than 8 hr duration.

For each of the three environmental media (air, water, and land), there are two sets of MATE values. The first, designated as health-based MATEs, is based on evidence of acute and chronic effects on humans and also on studies of animal toxicity. The ecology-based MATEs are derived from studies of pollutant effects on plant and aquatic life.

MATE values, therefore, can be a very useful tool by revealing potential environmental hazards in source assessment data. The SAM technique does not work in all cases, however, since there are many contaminants for which MATEs have not yet been established.

The SAM is basically a screening technique designed to provide a quantitative means of assessing the pollution potential of a process or source. The SAM format focuses on each separate effluent stream, whether it evolves from the process itself or associated pollution control equipment. The information resulting from the SAM procedure can provide the guidance required to progress from a Level 1 to a Level 2 source analysis program, where specific chemical compounds are targeted for study.

In the most basic version of SAM (designated as SAM-1A), which was used to evaluate the data in this report, the emitted contaminants are assumed to be noninteractive with the ambient environment (i.e., effluent components are released without transformation and are not involved in synergistic activities). Also, no assumption is made about the dispersion modes of individual pollutants to their receptor sites, except that such dispersion would have at least the equivalent effect of the safety factors which are normally applied when converting short-term exposure data to estimates of longer term chronic ambient exposure levels.

The SAM-1A approach compares each sample fraction or specific pollutant concentration in a given effluent stream to a corresponding MATE value. The ratio of these quantities is known as the degree of hazard (H) for that particular pollutant. Any contaminant whose H value is greater than unity is flagged as a potential problem pollutant. The product of a contaminant's H value and the effluent stream flow rate establishes that contaminant's Toxic Unit Discharge Rate (TUDR). The H values and TUDRs are summed for each effluent stream. This derived information can subsequently be used to rank effluent streams on the basis of the magnitude of their TUDRs, establish pollutant priorities and identify problem pollutants, and determine the need for control/disposal technology development.

BRAINTREE DATA

Four effluent streams from the Braintree incinerator system were monitored for this study. They were: (a) bottom ash from the traveling stoker grate; (b) bottom ash quench water; (c) collected ash from the ESP; and (d) flue gas emissions. The analytically determined constituents of each effluent stream were compared to their appropriate MATE values via the SAM-1A procedure. Completing the SAM-1A methodology, the cumulative degrees of hazard and toxic unit discharge rates were calculated for each stream. Results of these calculations are summarized in Table 36 and the data tables used in making these calculations are contained in Appendix D.

TABLE 36. SUMMARY OF RESULTS FROM SAM-1A METHODOLOGY

	Health based	Ecological based
	Degree of hazard	
Bottom ash	3,800	1,740,000
Quench water	< 20	< 0.2
ESP ash	1,300	200,000
Flue gas	14,000	110
	Toxic unit discharge rate	
Bottom ash (g/sec)	1,700,000	780,000,000
Quench water (liter/sec)	< 76	< 0.76
ESP ash (g/sec)	6,900	1,100,000
Flue gas (m^3/sec)	137,000	1,100

The summary of results indicate that the air emissions had the highest degree of hazard (health based), but that the bottom ash had the highest ecology-based H value. The two solid waste effluent streams (ESP ash and bottom ash) also produced the largest TUDRs in both categories, which is basically the result of the higher effluent stream flow rate of the bottom ash as compared to the other effluent streams. The units of measure prescribed in the SAM-1A procedure are intended to provide for an intercomparison of different types of effluent streams.

It should also be pointed out that the summations (Appendix D) included some "less than" and "greater than" values which make the cumulative totals somewhat inaccurate. For lack of a better strategy, the "less than" and "greater than" qualifiers were taken as absolute values in computing the summations, but are pointed out in the discussions below whenever they significantly affected the results.

Although the bottom ash stream had the highest health-based TUDR, its degree of hazard was lower than that of the flue gas, but higher than the ESP ash H value. The bottom ash was analyzed only for elemental composition. Those elements contributing most to the total degree of hazard (> 100) were Pb, Ba, Fe, Mn, and Cr, whose combined H value was 3,320. The bottom ash also yielded by far the highest ecological-based degree of hazard, at 1,740,000. One element, phosphorus, had an H value of 1,700,000 because of its low MATE concentration (0.001 μg/g) and completely outweighed the contributions of the other elements. It should be noted that the MATE value used was for elemental phosphorus and if the species of P were known, the hazard value may be significantly reduced. Ecological degrees of hazard were also high for several metals, namely Pb, Cd, Zn, Cu, Ni, Fe, Ti, and Al. And since the H (ecological) value for the bottom ash was high, the total stream TUDR was correspondingly very large.

The bottom ash quench water, being a small effluent stream and one which was accorded only a cursory analysis, yielded almost negligible SAM-1A results. Of the water quality parameters determined for this stream, only phenol had an assigned MATE value and therefore constituted the total stream H and TUDR values. This probably does not give a realistic indication of the true toxic potential of the quench water since additional analyses, such as for trace metals or other chemical compounds could yield a much greater degree of hazard.

The fly ash collected by the ESP had health-based H and TUDR values below those of both the bottom ash and the flue gas, but its ecological-based values were quite high. This was due to the concentrations of several metals as was the case with the bottom ash. They included Pb, Ba, Sb, Cd, Ag, As, Zn, Cu, Ni, Fe, Mn, Cr, V, Ti, P, Al, and Li. Once again the high concentration of P (> 1,000 μg/g) produced an H value which overshadowed the others (1 million). Also very high were Pb (5,000), Cd (18,500), Ni (10,000), and Mn (8,000). Every element for which an ecological-based MATE concentration was assigned had an H value greater than one.

The highest degree of hazard (health based), 14,000, resulted from SAM analysis of the incinerator flue gas. The corresponding ecological-based H value, however, was very low because very few ecological-based MATE values have been established for air emissions.

The high H (health) value computed for the flue gas stream can be seen from the data sheets to be due almost in total to the LC3 fraction of the XAD-2 resin extract and aqueous condensate (SASS train). Since the exact nature of the compounds in each LC fraction is not known (each LC fraction could be composed of anywhere between one and all of the compounds listed for that particular fraction), the SAM-1A procedure specifies use of the most conservative MATE value. In the case of fraction LC3, the designated MATE value is that for benzo[a]pyrene, 0.02 $\mu g/m^3$. So, in effect, the total concentration determined for LC3, 120 $\mu g/m^3$, is assumed to be benzo[a]pyrene, which is almost certainly not the case. Therefore, the degree of hazard for the flue gas stream may realistically be much lower than 14,000.

Only one other specific H (health) value was particularly large; that of chromium in the SASS aqueous condensate (1,500). Combined with the two LC3 fraction H (health) values of 6,000 and 6,050, these three concentrations account for 13,550 out of the total degree of hazard of 14,000. It should be noted, however, that some corrosion of the SASS train stainless steel components was evident and most likely could have contributed to the high Cr value.

Analysis of the flue gas for gaseous species (CO, NO_x, SO_2, etc.) also showed several constituents to be in excess of their respective MATE concentrations. CO, NO_x, and SO_2 each had degrees of hazard greater than one, although on a parts per million basis, the levels of SO_2 and NO_x seem relatively low (see Table 15). The CO concentration, however, did appear to be somewhat high. The results of applying the SAM methodology to these gases points out the conservative derivation of the MATE values.

The SAM-1A procedure was also applied to the results of the mercury/anion train. All of the anion concentrations measured, Cl^-, F^-, Br^-, and CN^-, had H (health) values much less than one. This was not the case with mercury, whose degree of hazard was 11.2 (health based) and 56 (ecological based).

Many of the constituents analyzed in each of the effluent streams had an H value greater than one, but many others had values much less than one. Therefore, the SAM-1A methodology does provide a means for identifying those pollutants which may or may not be of environmental concern. In this manner, it allows an environmental assessment process to be conducted that heretofore has not been available.

In summary, application of the SAM-1A assessment procedure to the Braintree Municipal Incinerator data permits the following conclusions to be drawn:

- Although the incinerator stack effluent appears to have the highest degree of hazard (health based) and would, therefore, be of primary environmental concern, further work is needed to identify the organic constituents in the XAD-2 resin extract and aqueous condensate fraction LC3. This could lead to a substantial reduction in the magnitude of the H value.

- The bottom ash had the highest toxic unit discharge rate, due primarily to the concentration of phosphorus and certain trace metals. The large TUDRs would seem to indicate that this effluent should receive the highest priority for control. However, considering the physical nature of this material and its method of disposal, it seems unlikely that it would be a major environmental problem. More conclusive data could be obtained from performing leachate tests on samples of the bottom ash to determine its true hazard potential under the worst of disposal conditions. To draw conclusions of environmental hazard simply on the basis of the SAM-1A results, demonstrates, at least in this particular case, a weakness of the SAM methodology.

- The bottom ash quench water was shown to be of negligible concern based on the SAM-1A results. However, this stream was not extensively analyzed and could, with additional data, prove to have a higher degree of hazard.

SECTION 6

DISCUSSION OF BRAINTREE COMPLIANCE TESTS

As stated previously in this report, particulate compliance tests have been conducted at the Braintree incinerator, both prior to and subsequent to the MRI test program. In each instance, the testing was performed by Air Quality Consultants (AQC) for the Town of Braintree under the general supervision of Metcalf and Eddy, Inc. It is the purpose of this section to present a summary of these results and to show the consistency of the emission values from the tests, even under different firing conditions.

Table 37 is a summary of three compliance tests conducted in November 1977, June 1978, and August 1978. It is important to note that, during the November tests, the refuse feed rate was 5 tons/hr (same as during the MRI program), whereas it was increased to 8 tons/hr for the July and August runs. In all three cases, the emission rates were within the state limitation of 0.10 gr/dscf.

It must also be pointed out that during these three tests emissions from the boiler were ducted to the ESP that was directly behind the boiler (i.e., emissions from Boiler No. 1 were ducted to ESP No. 1 and emissions from Boiler No. 2 were ducted to ESP No. 2). In the case of the MRI tests, emissions from Boiler No. 1 were ducted to ESP No. 2. This was done by MRI in order to enable sampling at the ESP inlet to establish the control efficiency of the ESP. The compliance tests did not include inlet sampling.

Some of the reasons that are hypothesized for the discrepancy between emission data obtained during the MRI tests and the other compliance tests are shown in the correspondence appended to this report (see Appendix E).

TABLE 37. SUMMARY OF BRAINTREE COMPLIANCE TEST RESULTS

Date	Operating mode	Refuse feed rate (tons/hr)	% O_2	%CO_2	Stack flow rate (dscfm)	Particulate emission rate (lb/hr)	Particulate concentration (gr/dscf)	Particulate concentration at 12% CO_2 (gr/dscf)
November 1977	Boiler No. 1 - ESP No. 1	5.4	15.7	3.9	15,800	1.85	0.014	0.042
June 1978	Boiler No. 1 - ESP No. 1	8	9.6	9.3	17,660	8.7	0.057	0.074
August 1978	Boiler No. 2 - ESP No. 2	8	12.9	7.0	17,370	8.1	0.055	0.094

SECTION 7

CONCLUSIONS

Based upon the data discussed in the preceding sections of this report, the following conclusions are presented to summarize the environmental assessment of the Braintree Municipal Incinerator. They are presented in general order of plant operation for each effluent stream.

BOTTOM ASH

- Elemental analysis of the glass- and metal-free ash revealed an overall increase in concentrations when compared to the refuse feed. Even the more volatile elements such as As, Sb, and particularly Pb were found to be concentrated in the bottom ash.

QUENCH WATER

- Levels of BOD, COD, oil and grease, TSS, and TDS indicate that some reduction in these water quality parameters might be desirable. The phenolic content was found to be < 0.1 mg/liter in all samples.

- Further analysis work should be carried out to more completely assess the total stream hazard potential, such as from trace metals and organic compounds which were not determined in this study.

ESP ASH

- The collector ash contained levels of chlorides, sulfates, and several trace elements which may be of concern. However, the leachability of the ash should be investigated to determine a more realistic hazard potential.

- PCBs were not detected in the ash and only very minimal levels of four PAH compounds were identified.

STACK EMISSIONS

- Emissions of hydrocarbons, NO_x, and SO_2 were low.

- High levels of CO in the stack gases could not be explained considering the large quantities of excess air used in the Braintree incinerator. Additional investigation to determine the cause of the CO emissions is warranted.

- Particulate concentrations exceeded both federal and State of Massachusetts regulations governing municipal incinerators. Average particulate concentration was 0.55 g/dscm (0.24 gr/dscf) corrected to 12% CO_2. The ESP removed only about 74% of the incoming particulate, while its design efficiency was reported to be 93%. Subsequent tests conducted for compliance purposes show an outlet loading of 0.074 g/dscf, indicating that ad hoc mechanical changes in plant operation could have an adverse effect on emissions.

- Levels of chlorides and other halides were low.

- The presence of PCBs was confirmed only in the SASS train XAD-2 resin, which yielded a concentration of 3.6 $\mu g/m^3$.

SAM-1A ASSESSMENT METHODOLOGY

- Results of the SAM-1A environmental assessment procedure show the incinerator stack emission to have the highest apparent degree of health hazard. Further analysis is needed to determine the exact composition of the organic components of the stack emissions to ascertain its true hazard potential.

- SAM-1A also showed that the bottom ash effluent had the largest TUDR, due primarily to the phosphorus and metals contained in this stream.

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APPENDIX A

ANALYTICAL PROCEDURES

PARTICULATE WEIGHT

Samples

Particulate weights were determined for the probe rinse, cyclone, and filters from the SASS train; probe rinse, cyclones, filter, carbon tetrachloride extract residue, and water residue from the collector outlet Method 5 trains; and probe rinse, filter, carbon tetrachloride extract residue, and water residue from the collector inlet Method 5 trains. Laboratory and field blanks were also included in the analyses. These blanks include: filters, rinse and extraction solvents, and water used to fill the impingers.

General Methods

Liquid samples were transferred to previously dessicated and tared beakers and evaporated to dryness. Water impingers from the Method 5 trains were extracted with CCl_4 and evaporated to dryness.

Specific Methods

Filter--

Gelman type A/E (fiberglass) filters for the Method 5 and SASS trains were tared in a constant humidity environment. After testing, the filters were equilibrated at a constant humidity and were reweighed to determine the weight of particulates on the filter.

Probe Rinses--

Acetone was used to rinse the probes of the Method 5 trains. The rinse from the front half of the filter holder was included in the probe rinse. These rinses were evaporated as separate samples and included as part of the front half weight. For the SASS train, methylene chloride and methanol (1:1 v/v) were used to rinse the probe, cyclone connecting lines, and front half of the filter holder. Cyclone catches and rinses from the SASS train were prepared in the same way as the probe rinses.

Method 5 Impingers--

Prior to analysis, all glassware to be used in this procedure was rinsed with reagent grade CCl_4. Contents of the bottled sample(s) were poured into a clean, CCl_4-rinsed, 4-liter separatory funnel. Appropriate amounts of CCl_4 (125 ml for every 450 ml of sample) were added in 100-ml increments. The funnels were shaken 25 times after each addition, and the layers allowed to separate. The CCl_4 extracts were collected in a single, acid-washed volumetric flask, and the water was drained into a clean, acid-washed bottle.

The CCl_4 extracts were transferred to a previously dessicated and tared beaker and evaporated to dryness under a stream of N_2. The water was poured into a similarly treated beaker and evaporated to dryness on a steam bath.

Sample Analysis

Filters and dried samples in beakers were dessicated overnight, equilibrated at constant temperature and humidity for 3 hr and weighed to the nearest 0.1 mg on an analytical balance.

Quality Assurance

Field blanks of filters, methylene chloride, acetone, and water were prepared with the samples. Laboratory blanks consisting of CCl_4 and control beakers were also prepared and weighed at the same time as the samples. The tare weights and final weights of the filters were made by the same individual. The balance was calibrated daily using NBS weights. Multiple weighings of dried sample materials to constant weight were performed to assure accurate weight determinations.

Problems

Acetone probe rinses were not extracted with carbon tetrachloride due to the miscibility of the two solvents, which precluded separation of two phases.

TABLE A-1. SUMMARY OF METHOD 5 PARTICULATE CATCH

Sample numbers	Run	Cyclone catch weight (g)	Filter catch weight (g)	Probe rinse particulate weight (g)	Impinger particulate weight[a/] (g)	Extractable weight[a/] (g)	Total corrected particulate weight[a/] (g)
100-104	1-I	0.5670	0.4132	0.3913	0.1058	0.0078	1.4851
105-108	1-0	-	0.4501	0.3120	0.1038	0.0126	0.8785
126-130	2-I	0.5834	0.4591	0.3875	0.0842	0.0059	1.5201
131-134	2-0	-	0.4309	0.3149	0.0797	0.0067	0.8322
152-156	3-I	0.7512	0.5222	0.5849	(0.0041)[b/]	0.0022	(1.8646)[b/]
157-160	3-0	-	0.3249	0.2053	0.0558	0.0030	0.5890

a/ Blank corrected values.
b/ Approximately 50% of the water impinger sample was lost due to equipment failure.

TABLE A-2. PROBE RINSE PARTICULATE WEIGHTS

Sample	Uncorrected particulate weight (g)	Blank weight (g)	Corrected particulate weight (g)
I-1	0.39305 ± 0.00015	0.00178	0.3913
I-0	0.3131 ± 0.0000	0.00111	0.3120
2-I	0.3899 ± 0.0002	0.00238	0.3875
2-0	0.3170 ± 0.0000	0.00211	0.3149
3-I	0.57145 ± 0.00005	0.00651	0.5849
3-0	0.20955 ± 0.00015	0.00428	0.2053

TABLE A-3. IMPINGER PARTICULATE WEIGHTS

Sample	Uncorrected particulate weight (g)	Blank weight (g)[b/]	Corrected particulate weight (g)
1-I	0.1085 ± 0.0009	0.00275	0.1058
1-0	0.10715 ± 0.00095	0.00336	0.1038
1-Blank	0.0024 ± 0.0000		
2-I	0.0874 ± 0.0003	0.003175	0.0842
2-0	0.08335 ± 0.00035	0.00361	0.0797
2-Blank	0.00305 ± 0.00005		
3-I	(0.0079 ± 0.0000)[a/]	0.00384	(0.0041)[a/]
3-0	0.05965 ± 0.00015	0.00380	0.0558
3-Blank	0.00225 ± 0.00005		

a/ Approximately 50% of the sample was lost due to equipment failure.
b/ Volume corrected.

TABLE A-4. CARBON TETRACHLORIDE EXTRACTABLE WEIGHTS

Sample	Uncorrected extractable weight (g)	Blank weight (g)	Corrected extractable weight (g)
1-I	0.0080 ± 0.0002	0.00025 ± 0.00005	0.0078
1-0	0.01285 ± 0.00025	0.00025 ± 0.00005	0.0126
1-Blank	0.0025 ± 0.00005		
2-I	0.0065 ± 0.0000	0.0006 ± 0.0001	0.0059
2-0	0.0073 ± 0.0000	0.0006 ± 0.0001	0.0067
2-Blank	0.0006 ± 0.0001		
3-I	0.00415 ± 0.00015	0.00195 ± 0.00005	0.0022
3-0	0.0049 ± 0.0001	0.00195 ± 0.00005	0.0030
3-Blank	0.00195 ± 0.00005		

TABLE A-5. SASS TRAIN PARTICULATE CATCH SUMMARY

Component	Load (g)
10 μ Cyclone	0.6164
3 μ Cyclone	1.2250
1 μ Cyclone	0.3297
Filter catch	1.3162
Front-half rinse	0.3113
Total particulate weight	3.7986

METALS ANALYSIS

Introduction

Particulates from Method 5 filters and ESP ash were analyzed for a series of seven metals; components of a SASS train were analyzed for antimony, arsenic, and mercury; and the impingers from the mercury train were analyzed for mercury. Because of visible corrosion of the stainless steel on the SASS collection system, and because stainless steel might therefore contribute significant amounts of antimony, arsenic, and mercury to the collection components, the SASS components were also analyzed for iron, chromium, and nickel to obtain an estimate of the extent of stainless steel contamination.

The samples were analyzed by three AAS techniques. Mercury was measured by cold vapor generation; antimony and arsenic by hydride generation; and all other elements were measured by flame techniques.

Sample Preparation

The digestion methods used for each sample type are described in the following sections. (All acids were used in the concentrated form unless otherwise noted.)

Method 5 Filters and ESP Ash--

The filters were reweighed and sectioned. Each section was weighed; the area of the section was calculated; and a calculated tare weight was subtracted to yield a particulate weight. A 0.2-g portion of the ESP ash was weighed.

The weighed samples were refluxed with 25 ml aqua regia (AR), centrifuged, rinsed three times with 5% HNO_3 (v/v), evaporated to < 25 ml, then diluted to 25 ml volume with deionized water. After digestion, the samples were analyzed for Sb, As, Cd, Cu, Fe, Pb, and Hg.

Mercury Train Impingers--

The impingers containing potassium hydroxide (KOH) and potassium permanganate ($KMnO_4$) were analyzed for mercury. Aliquots of each sample, as well as all the mercury standards, were gently refluxed for 2 hr with 5 ml HNO_3 and at least 5 ml of 3% (w/v) $KMnO_4$. After digestion, the excess $KMnO_4$ was reduced with 10% (w/v) hydroxylamine hydrochloride, 2 ml of 10% (w/v) stannous chloride ($SnCl_2$) were added, and the sample was analyzed for mercury by the cold vapor method.

SASS--

The components of the SASS train were analyzed separately for antimony, arsenic, and mercury. The Level 1 digestion protocol as modified by A. D. Little was used for these elements, but analysis was completed by hydride generation (As, Sb) and cold vapor (Hg) techniques. The following sample preparation procedures were used:

Antimony--Twenty-five milliliter aliquots of all samples were digested with 7 ml of 9 M H_2SO_4 and 5 ml concentrated HNO_3. The samples were heated to fumes of SO_3, cooled, 25 ml deionized water added, reheated to SO_3 fumes, cooled, and diluted to 50 ml volume with deionized water.

Arsenic--

(1) Twenty-five milliliter aliquots of the aqueous condensate, peroxide impinger, and oxygen bombed XAD-2 resin samples were digested with 10 ml concentrated H_2SO_4 and 10 ml HNO_3. The samples were heated to the fume stage of H_2SO_4, cooled, 5 ml of deionized water added, reheated to fumes of SO_3, cooled, and diluted to 50 ml with deionized water.

(2) Twenty-five milliliter aliquots of ammonium persulfate-silver nitrate impingers were diluted to 50 ml with deionized water.

Mercury--

(1) Ten milliliters of concentrated HNO_3 were added to aliquots of aqueous condensate and peroxide impingers. A 3% (w/v) $KMnO_4$ solution wazs added dropwise until the prepared aliquots remained pink.

(2) Ten milliliters of concentrated HNO_3 and 2 ml of concentrated hydrochloric acid (HCl) were added to aliquots of the ammonium persulfate impingers. The treated aliquots were then filtered through a No. 41 Whatman filter, the filter washed with deionized water, and the filtrate diluted to 50 ml volume with deionzied water.

(3) A 3% (w/v) $KMnO_4$ solution was added to aliquots of the oxygen bombed XAD-2 resin until a purple color persisted.

Corrosion Test of SASS Train--

Aqueous condensate and impinger solution components of the SASS train were analyzed for the major components of stainless steel. Portions of these samples were refluxed with 10 ml HNO_3, evaporated to < 10 ml, then diluted to 10 ml volume with deionized water, and analyzed for Fe, Cr, and Ni.

Sample Analysis

Three AAS techniques were used for the analysis of samples prepared according to methods described in the previous section.

Flame AAS--

A Varian AA-6 atomic absorption spectrophotometer, equipped with background correction, was used to analyze samples for Cd, Cu, Fe, and Pb. The samples were aspirated into an air-acetylene flame.

Cold Vapor Generation--

Aliquots of prepared samples were analyzed for mercury. Prior to analysis, permanganate digestions of the mercury train samples were cleared with 10% (w/v) hydroxylamine hydrochlroide. Sample aliquots were pipetted into a reaction tube, diluted to 60 ml with deionized water, and 2 ml of 10% (w/v) $SnCl_2$ was added to reduce the mercury to elemental mercury. The sample was then purged with air introduced through a glass frit, sweeping the mercury vapor into a quartz-windowed analysis cell. The analysis was performed on a Varian AA-6 spectrometer using background correction.

Hydride Generation--

Aliquots of prepared samples for arsenic analysis were placed in a reaction jar with 20 ml of 50% (v/v) HCl. A reducing solution, 1 ml of 10% sodium borohydride in 10% sodium hydroxide, was injected to produce the gaseous hydride. A 10-sec reaction time was allowed (with stirring) before the hydride was swept into a hydrogen-nitrogen-entrained air flame on a Varian AA-6 spectrometer. Antimony was analyzed as above, with the exception that 10 ml of 10% (w/v) sodium iodide was added to the acidified aliquot and allowed to react for 3 min before injection of the reducing solution. Background correction was employed for both analyses.

Quality Assurance

Every digestion included two acid reagent blanks (to determine contamination levels from the acids used) and two fortified acid reagent blanks (to determine any loss of the analyte). All measured values of the analyte were corrected for reagent background. The filter digestion included filter blanks which provide measured values of background metal contributions from the filter to be used for correction of metal concentrations.

The Method 5 filters and ESP ash were analyzed in duplicate, or were fortified prior to digestion for recovery data. Since the metal concentrations were unknown, several samples were fortified at levels too low for good recovery calculations. As a result, the concentrations were verified by the method of standard additions. SRMs similar to the samples were used to monitor digestions efficiency. The primary standard for refuse was Bureau of Mines Refuse.

Duplicate portions of the mercury train samples were analyzed. Samples from KOH and $KMnO_4$ impingers were fortified prior to digestion. The SASS train measurements were verified by the method of standard additions.

TABLE A-6. QUALITY ASSURANCE FOR ANTIMONY

Sample	Concentration (μg/g)	Deviation (μg/g)	Fortification (μg/g)	Recovery (%)	Standard addition value (μg/g)
1-I	2,200	300	-	-	
1-O	1,300	200	-	-	
2-I	1,600	-	a/	a/	1,600
2-O	880	-	a/	a/	1,000
3-I	940	150	-	-	
3-O	1,800	100	-	-	
1-ESP Ash	615	5	a/	a/	
2-ESP Ash	240	20	a/	a/	180
3-ESP Ash	91	5	a/	a/	
Reagent blank			-	-	
Filter blank			0.016 b/	81	

a/ Fortification level too low for recovery.
b/ This concentration is given in micrograms per milliliters.

TABLE A-7. QUALITY ASSURANCE FOR ARSENIC

Sample	Concentration (μg/g)	Deviation (μg/g)	Fortification (μg/g)	Recovery (%)	Standard addition value (μg/g)
1-I	170	10	-	-	
1-O	151	0	-	-	
2-I	240	-	a/	a/	190
2-O	100	-	a/	a/	66
3-I	224	2	-	-	
3-O	180	10	-	-	
1-ESP Ash	57	4	a/	a/	
2-ESP Ash	19	1	12.2	115	18
3-ESP Ash	11	0	9.82	125	
Reagent blank	-	-	0.08 b/	105, 95	
Filter blank	-	-	0.08 b/	98, 122, 89	

a/ Fortification level too low for recovery.

b/ This concentration is given in micrograms per milliliters.

TABLE A-8. QUALITY ASSURANCE FOR MERCURY

Sample	Concentration (μg/g)	Deviation (μg/g)	Fortification (μg/g)	Recovery (%)	Standard addition value (μg/g)
1-I	65	2	-	-	
1-O	114	1	-	-	
2-I	21	-	23.6	115	
2-O	160	-	a/	a/	
3-I	38	7	-	-	
3-O	97	1	-	-	110
1-ESP Ash	23	1	31.8	110	
2-ESP Ash	25	3	36.7	113	
3-ESP Ash	12	1	29.5	88	
Reagent blank	-	-	0.24 b/	83, 90	
Filter blank	-	-	0.24 b/	91, 87, 84	

a/ Fortification level too low for recovery.
b/ This concentration is given in micrograms per milliliters.

TABLE A-9. QUALITY ASSURANCE FOR IRON

Sample	Concentration (μg/g)	Deviation (μg/g)	Fortification (μg/g)	Recovery (%)	Standard addition value (μg/g)
1-I	3,900	200	-	-	
1-O	4,200	300	-	-	
2-I	3,200	-	17,700	100	
2-O	3,800	-	15,500	54	
3-I	3,600	30	-	-	
3-O	3,720	10	-	-	
1-ESP Ash	17,400	700	15,900	128	
2-ESP Ash	23,000	1,000	18,300	137	
3-ESP Ash	20,700	200	14,700	122	
Reagent blank	-	-	120[a]	83,85	
Filter blank	-	-	120[a]	84,108,65	

a/ This concentration is given in micrograms per milliliters.

TABLE A-10. QUALITY ASSURANCE FOR LEAD

Sample	Concentration (μg/g)	Deviation (μg/g)	Fortification (μg/g)	Recovery (%)	Standard addition value (μg/g)
1-I	41,800	300	-	-	
1-O	46,000	6,000	-	-	
2-I	45,700	-	a/	a/	53,200
2-O	34,600	-	a/	a/	36,800
3-I	62,000	3,000	-	-	
3-O	63,000	2,000	-	-	
1-ESP Ash	15,400	100	5,300	80	
2-ESP Ash	10,800	200	6,110	103	
3-ESP Ash	3,900	100	4,910	111	
Reagent blank	-	-	40 b/	93, 100	
Filter blank	-	-	40 b/	95, 100	

a/ Fortification level too low for recovery.

b/ This concentration is given in micrograms per milliliters.

TABLE A-11. QUALITY ASSURANCE FOR CADMIUM

Sample	Concentration (μg/g)	Deviation (ppm)	Fortification (μg/g)	Recovery (%)	Standard addition value (μg/g)
1-I	2,900	200	-	-	
1-O	2,300	200	-	-	
2-I	1,400	-	a/	a/	1,200
2-O	950	-	a/	a/	960
3-I	1,380	90	-	-	
3-O	1,230	20	-	-	
1-ESP Ash	700	100	a/	a/	
2-ESP Ash	223	4	122	95	270
3-ESP Ash	54	1	98.2	110	
Reagent blank	-	-	0.8 b/	100, 98	
Filter blank	-	-	0.8 b/	104, 94, 106	

a/ Fortification level too low for recovery.
b/ This concentration is given in micrograms per milliliters.

TABLE A-12. QUALITY ASSURANCE FOR COPPER

Sample	Concentration (µg/g)	Deviation (µg/g)	Fortification (µg/g)	Recovery (%)	Standard addition value (µg/g)
1-I	1,580	50	-	-	
1-O	1,200	100	-	-	
2-I	1,970	-	a/	(a)	1,970
2-O	1,430	-	a/	(a)	1,320
3-I	1,490	20	-	-	
3-O	1,470	50	-	-	
1-ESP Ash	740	10	a/	a/	
2-ESP Ash	1,900	100	a/	a/	2,190
3-ESP Ash	970	20	a/	a/	
Reagent blank	-	-		-	
Filter blank	-	-	1.2 b/	117, 100, 100	

a/ Fortification level too low for recovery.
b/ This concentration is given in micrograms per milliliters.

TABLE A-13. RESULTS OF SASS TRAIN METALS ANALYSES, RUN 2

Element	Condenser water (mg)	Impinger 1 (mg)	Impinger 2 (mg)	Impinger 3 (μg)
Iron	168	285	15.9	630
Chromium[a/]	44.8	69.6	3.61	140
Nickel	28.8	50.6	2.59	70

Element	10 μ Cyclone (μg/g)	3 μ Cyclone (μg/g)	1 μ Cyclone (μg/g)	Filter (μg/g)[b/]	XAD-2 Resin (μg/g)
Antimony	183	555	835	771	< 3
Arsenic	56.5	89.8	58.5	126	< 9
Mercury	147	14.2	5.56	< 4	3.29[c/]

Element	Condenser Water (μg)	Impinger 1 (μg)	Impinger 2 (μg)	Impinger 3 (μg)
Antimony	< 15	37.9	< 18	< 13
Arsenic	42.3	130	< 15	< 11
Mercury	373	921	300	305

Note: The results are reported in three significant figures for further calculation purposes only; the results are good to only two significant figures.

a/ Chromium reagent blank was subtracted from the reported values.

b/ The filter blank was subtracted before the calculation of the reported value.

c/ The resin blank was subtracted from the reported value.

TABLE A-14. MERCURY TRAIN ANALYSIS QUALITY ASSURANCE DATA

Sample	Sample mercury background content (μg/ml)a/	Fortification concentration (μg/ml)	Recovery (%)b/
KOH Field Sample	0.0027	0.023, 0.028	117, 96
KOH Blanks	< 0.002	0.020, 0.020	118, 90
$KMnO_4$ Field Sample 1B	0.034	0.053	123
$KMnO_4$ Field Sample 2A	0.0042	0.032	89
$KMnO_4$ Blanks	< 0.002	0.020, 0.017	104, 102

a/ Average values, without blank correction.

b/ $\frac{\text{Observed Fortification Concentration}}{\text{Added Fortification Concentration}} \times 100\%$

ELEMENTAL COMPOSITION (SSMS)

Samples

All input and outlet streams were analyzed by SSMS for elemental composition. Samples of refuse, bottom ash, collector inlet particulate, collector ash, and collector outlet particulate were analyzed for each test day. Outlet gas samples, including size classified particulate, XAD-2 resin, aqueous condensate, and hydrogen peroxide impinger solutions, collected with a SASS train during one test day were also analyzed by SSMS.

Quality assurance samples for precision determinations included analysis of blind duplicate samples of refuse, bottom ash, collector inlet particulate, collector ash, and collector outlet particulate. SRMs, when available, were analyzed as unknown samples to determine analytical accuracy. SRMs which were analyzed included: NBS fly ash (SRM 1633) and Bureau of Mines refuse. Samples of aqueous condensate, hydrogen peroxide, and XAD-2 resin were fortified with selected metals to determine analytical accuracy for these three sample types because suitable SRMs were not available. Blanks of XAD-2 resin, Gelman A/E fiberglass filter, and hydrogen peroxide solution were also analyzed.

EPA Level 1 assessment was performed on outlet gas samples from this process. The SSMS analysis for elemental composition required by Level 1 is included with the other samples mentioned above. The Level 1 elemental composition is discussed in this section.

All SSMS analyses were subcontracted to CDM/Accu-Labs, Wheat Ridge, Colorado.

Sample Preparation

Sample preparation of materials with high organic content involved acid digestion followed by combination with high purity graphite. The mixture was subsequently dried. Samples of XAD-2 resin were digested using the prescribed Level 1 oxygen bomb decomposition method.

Solid inorganic samples were directly combined with graphite. Solid samples having a high organic content were ashed prior to combination with graphite. In the case of liquids, the samples were directly combined with graphite and dried. After drying, all sample graphite mixtures were formed into electrodes for analysis. All digestions, graphite mixing, drying, and electrode formations were performed by CDM/Accu-Labs.

Prior to analysis, refuse, bottom ash, and collector ash samples were dried and ground by Industrial Testing Laboratories, Kansas City, Missouri. Aliquots were placed in acid-washed bottles and shipped for SSMS analysis. All aqueous samples, reference materials, and XAD-2 resin were aliquotted and shipped for SSMS analysis without additional pretreatment.

Fortified samples were prepared by addition of AA standard solutions in known quantities. For aqueous samples, a final known fortification level was prepared by dilution to a known final volume.

Fortified XAD-2 resin was prepared by addition of AA standards to a known weight of resin. The complete slurried mixture was subsequently treated as a single charge in an oxygen bomb method by CDM/Accu-Labs.

Analytical Method

All SSMS elemental analyses were performed on an AEI MS 702 mass spectrometer equipped with a photographic plate detector. All quantitative determinations were accomplished by direct visual comparison against standard reference plates.

Quality Assurance

A variety of samples were analyzed to monitor analytical accuracy and precision. NBS reference fly ash (SRM 1633) and Bureau of Mines refuse were employed as primary monitors of analytical accuracy. Possible sample matrix interferences in aqueous condensate, hydrogen peroxide solution, and XAD-2 resin were monitored through samples fortified with known quantities of the metals of interest to this test. To monitor analytical precision, blind duplicate samples of refuse, bottom ash, collector ash, collector inlet particulate and collector outlet particulate were submitted for analysis. The results are reported in the respective analysis section. All quality assurances samples were submitted without origin identity.

Results for reference materials analyses are summarized in Tables A-15 and A-16 for Bureau of Mines refuse and NBS fly ash (SRM 1633). Observed refuse elemental concentrations were compared to elemental concentration ranges reported in Bureau of Mines Publications No. RI 8244 and elemental concentrations observed for a previous SSMS analysis of the reference refuse material performed by CDM/Accu-Labs. Generally, agreement of the observed values with the reported concentration ranges was good.

TABLE A-15. BUREAU OF MINES REFUSE SSMS ANALYSIS

Element	Concentration[a] Observed value	Previously[b] reported value	Average	Deviation	Reported[e] range
Uranium	0.15	0.16	0.16	0.01	NR[c]
Thorium	1.0	0.63	0.82	0.19	NR[c]
Bismuth	16	3.9	5.0	1.1	< 15
Lead	430	180	300	130	160
Thallium	< 0.1	< 0.13	< 0.13	-	NR[c]
Mercury	0.74	NR[c]	NR[c]	-	NR[c]
Gold	< 0.1	< 0.1	< 0.1	-	NR[c]
Platinum	< 0.1	< 0.1	< 0.1	-	NR[c]
Iridium	< 0.1	< 0.1	< 0.1	-	NR[c]
Osmium	< 0.1	< 0.1	< 0.1	-	NR[c]
Rhenium	NR[c]	NR[c]	NR[c]	-	NR[c]
Tungsten	≤ 1.4	0.80	≤ 1.1	-	NR[c]
Tantalum	22[d]	< 0.1	≤ 11[d]	-	NR[c]
Hafnium	≤ 0.41	0.35	≤ 0.38	-	NR[c]
Lutecium	≤ 3.2	< 0.1	≤ 1.6	-	NR[c]
Ytterbium	≤ 10	0.17	≤ 5.1	-	NR[c]
Thulium	≤ 0.16	< 0.1	≤ 0.13	-	NR[c]
Erbium	≤ 1.1	0.16	≤ 0.63	-	NR[c]
Holmium	< 0.1	< 0.1	< 0.1	-	NR[c]
Dysprosium	≤ 2.0	0.17	≤ 1.0	-	NR[c]
Terbium	≤ 1.6	0.18	≤ 0.89	-	NR[c]
Gadolinium	≤ 7.8	0.29	≤ 4.0	-	NR[c]
Europium	≤ 2.3	0.11	≤ 1.2	-	NR[c]
Samarium	1.5	0.92	1.2	0.3	NR[c]
Neodymium	3.7	1.0	2.4	1.4	NR[c]
Praseodymium	2.0	1.4	1.7	0.3	NR[c]
Cerium	19	4.9	12	7.0	NR[c]
Lanthanum	8.6	1.3	5.0	3.6	NR[c]
Barium	> 10,000	200	≥ 5,100	-	< 20-400
Cesium	1.3	0.15	0.73	0.58	NR[c]
Iodine	0.35	< 0.1	≤ 0.23	-	NR[c]
Tellurium	< 0.1	< 0.1	< 0.1	-	NR[c]
Antimony	34	5.4	20	15	5.9
Tin	110	68	89	21	< 20
Indium	NR[c]	NR[c]	NR[c]	NR[c]	NR[c]
Cadmium	1.2	0.97	2.2	1.2	< 2-6
Silver	4.0	2.7	2.4	0.3	< 3-5
Palladium	< 0.1	< 0.1	< 0.1	-	NR[c]
Rhodium	< 0.1	< 0.1	< 0.1	-	NR[c]
Ruthenium	< 0.1	< 0.1	< 0.1	-	NR[c]
Molybdenum	2.5	8.7	5.6	3.1	NR[c]

(continued)

TABLE A-15. (continued)

Element	Concentration[a] Observed value	Previously[b] reported value	Average	Deviation	Reported[e] range
Niobium	5.0	12	8.5	3.5	NR[c]
Zirconium	22	55	38	17	NR[c]
Yttrium	4.5	0.97	2.7	1.8	NR[c]
Strontium	500	58	280	220	16
Rubidium	22	4.7	13	8.7	NR[c]
Bromine	5.9	6.3	6.1	0.2	NR[c]
Selenium	0.34	0.17	0.26	0.09	NR[c]
Arsenic	1.9	4.1	3.2	1.0	NR[c]
Germanium	< 0.1	< 0.1	< 0.1	-	NR[c]
Gallium	1.7	3.6	2.6	0.9	NR[c]
Zinc	∿ 1,800	440	∿ 1,100	∿ 680	250
Copper	180	94	140	46	62
Nickel	14	44	29	15	59
Cobalt	3.2	2.0	2.6	0.6	7.8
Iron	> 5,000	∿ 1,600	≥ 3,300	-	1,600
Manganese	180	210	200	20	85
Chromium	110	330	200	130	15-237
Vanadium	160	7.3	84	76	NR[c]
Titanium	∿ 2,300	> 5,000	≥ 3,600	-	1,620-3,420
Scandium	0.85	0.42	0.64	0.22	NR[c]
Calcium	5,900	> 0.5%	> 0.75%	-	0.15%-0.74%
Potassium	1,400	> 5,000	≥ 2,900	-	475-1,420
Chlorine	130	74	100	28	NR[c]
Sulphur	> 5,000	∿ 1,000	≥ 3,000	-	NR[c]
Phosphorus	640	∿ 1,900	∿ 1,300	∿ 630	NR[c]
Silicon	> 1%	> 1%	> 1%	-	NR[c]
Aluminum	7,000	> 0.5%	> 0.5%	-	0.55%-1.3%
Magnesium	760	> 5,000	≥ 3,400	-	534-1,100
Sodium	2,100	∿ 3,600	≥ 4,300	-	1,150-4,010
Fluorine	22	130	76	54	NR[c]
Oxygen	NR[c]	NR[c]	NR[c]	-	NR[c]
Nitrogen	NR[c]	NR[c]	NR[c]	-	NR[c]
Carbon	NR[c]	NR[c]	NR[c]	-	NR[c]
Boron	NR[c]	39	-	-	NR[c]
Beryllium	< 0.1	< 0.1	< 0.1	-	< 2
Lithium	5.8	24	15	10	< 2-3

a/ All values in microgram per gram except where noted.
b/ Values previously reported for the same material analyzed by CDM/ACCU-LABS by SSMS.
c/ Not reported.
d/ Possible source contamination.
e/ Range based on data from B. W. Haynes, S. L. Law, W. J. Campbell, "Metals in the Combustible Fraction of Municipal Solid Waste," U.S. Bureau of Mines Publication, RI 8244, 1977.

TABLE A-16. NBS FLY ASH SRM 1633 SSMS ANALYSIS

Element	Concentration[a] Observed value	Concentration[a] Reported value	Recovery (%)
Uranium	5.8	11.6 ± 0.2[b]	50
Thorium	17	24.8 ± 2.2[c]	69
Bismuth	2.9	NR[d]	-
Lead	260	70 ± 4	371
Thallium	4.0	(4)[d]	100
Mercury	NR[e]	0.14 ± 0.01[b]	-
Gold	< 0.1	NR[e]	-
Platinum	< 0.1	NR[e]	-
Iridium	< 0.1	NR[e]	-
Osmium	< 0.1	NR[e]	-
Rhenium	NR[e]	NR[e]	-
Tungsten	2.5	4.6 ± 1.6[c]	54
Tantalum	1.8	1.8 ± 0.3[c]	100
Hafnium	7.0	7.9 ± 0.4[c]	89
Lutecium	0.79	1.0 ± 0.1[c]	79
Ytterbium	4.0	7 ± 3[c]	57
Thulium	1.8	NR[e]	-
Erbium	6.4	NR[e]	-
Holmium	2.9	NR[e]	-
Dysprosium	7.2	NR[e]	-
Terbium	1.1	1.9 ± 0.3[c]	58
Gadolium	4.0	NR[e]	-
Europium	2.7	2.5 ± 0.4[c]	108
Samarium	6.2	12.4 ± 0.9[c]	50
Neodymium	29	NR[e]	-
Praseodymium	27	NR[e]	-
Cerium	350	146 ± 15[c]	240
Lanthanum	96	82 ± 2[c]	117
Barium	~ 3,200	2,700 ± 200[c]	119
Cesium	10	8.6 ± 1.1[c]	115
Iodine	1.7	2.9 ± 1.2[c]	59
Tellurium	< 0.12	NR[e]	-
Antimony	7.8	6.9 ± 0.6[c]	113
Tin	4.6	NR[e]	-
Indium	NR[e]	NR[e]	-
Cadmium	0.97	1.45 ± 0.06[e]	67
Silver	0.17	NR[e]	-
Palladium	< 0.1	NR[e]	-
Rhodium	< 0.1	NR[e]	-
Ruthenium	< 0.1	NR[e]	-
Molybdenum	37	NR[e]	-
Niobium	32	NR[e]	-

(continued)

TABLE A-16. (continued)

Element	Concentration[a] Observed value	Concentration[a] Reported value	Recovery (%)
Zirconium	550	301 ± 20[c]	183
Yttrium	51	62 ± 10[c]	82
Strontium	∿ 1,300	1,700 ± 300[c]	76
Rubidium	240	125 ± 10[c]	192
Bromine	28	12 ± 4[c]	233
Selenium	14	9.4 ± 0.3[b]	149
Arsenic	20	61 ± 6[b]	33
Germanium	14	NR[e]	-
Gallium	15	NR[e]	-
Zinc	210	210 ± 20[b]	100
Copper	150	128 ± 5[b]	117
Nickel	56	98 ± 3[b]	57
Cobalt	38	41.5 ± 1.2[c]	92
Iron	> 1%	6.2% ± 0.3%[c]	(> 16)
Manganese	280	493 ± 7[b]	57
Chromium	150	131 ± 2[b]	115
Vanadium	210	214 ± 8[b]	98
Titanium	∿ 7,400	7,400 ± 300[c]	100
Scandium	13	27 ± 1[c]	48
Calcium	> 1%	4.7% ± 0.6%[c]	(> 21)
Potassium	> 1%	1.61% ± 0.15%[c]	(> 62)
Chlorine	230	42 ± 10[c]	548
Sulphur	∿ 4,800	NR[e]	-
Phosphorus	∿ 1,400	NR[e]	-
Silicon	> 1%	21% ± 2%[c]	(> 5)
Aluminum	> 1%	12.7% ± 0.5%[c]	(> 8)
Magnesium	> 1%	1.8% ± 0.4%[c]	(> 56)
Sodium	850	3,200 ± 400[c]	27
Fluorine	350	NR[e]	-
Oxygen	NR[e]	NR[e]	-
Nitrogen	NR[e]	NR[e]	-
Carbon	NR[e]	NR[e]	-
Boron	390	NR[e]	-
Beryllium	1.2	(12)[d]	10
Lithium	160	NR[e]	-

a/ All values in micrograms per gram except where noted.

b/ NBS certified value.

c/ Value reported by J. M. Ondov, et al., Anal. Chem., 47(7), 1102 (1975).

d/ Uncertified NBS value.

e/ Not reported.

Elements having observed levels in excess of the reported range included: Pb, Ba, Sn, Sr, Zn, Cu, Fe, Mn, Ca, Mg, Na, and Li. The values for Mn, Ca, Mg, Na, and Li are only slightly greater than the reported ranges and would appear to be within reasonable agreement. The excessively high values for Fe, Ca, Mg, Na, and Li would appear to be due to operation at the extreme high concentration limit of the quantitative scale. The high value for copper may be due to inhomogeneous distribution of this element in this refuse sample. This observation has been reported in Bureau of Mines Publication RI 8244. Explanations for the high values observed for Pb, Ba, Sn, Sr, and Zn, and the variability of V values are unknown.

Metal concentrations observed in NBS fly ash (SRM 1633) were compared to certified and uncertified values reported by NBS and additional values reported by Ondov et al., in Anal. Chem., 47(7):1102 (1975). Generally, good agreement between observed and reported values was found. High recovery values (>150%) were found for Pb, Ce, Zn, Rb, Br, and Cl. Of the elements having high recoveries, only Pb is certified by NBS, which suggests the remaining elements may be inhomogeneously dispersed in the reference materials producing variable results. Elements having low recoveries are generally alkali or alkaline earth materials of major or minor concentrations beyond the quantitative analytical capabilities of the technqiue. Low values for As may be due to loss of volatile arsenic species in the spectrometer vacuum system. The low recovery of Be and Sc remain unexplained; however, neigher comparison value is certified by NBS which may be indicative of inhomogeneous distribution of these elements in the SRM.

Analytical accuracy and sample matrix interferences were monitored through the use of fortified samples of aqueous condensate, hydrogen peroxide solution, and XAD-2 resin. The fortifications were accomplished using AA standards for the metals of interest. Fortification quantities added and recovery of them are summarized in Tables A-17 to A-19 for aqueous condensate, hydrogen peroxide solution, and XAD-2 resin, respectively. In all cases, fortification recoveries were highly variable, which may be indicative of several problems.

The high recovery values observed for the fortified aqueous condensate sample are generally attributable to the insufficient quantity of metal added. The very high sample background levels of Fe, Cn, and Ni have been attributed to the corrosion of the SASS train during sampling. As a result, values for Fe, Cr, and Ni appear to be unreliable.

Similar observations can be made for the fortified hydrogen peroxide solution. Recoveries of Cr, Cu, Fe, and Zn are poor due to the insufficient fortification quantities used. In both the aqueous condensate and the peroxide solution lead fortifications were not observed. Additional SSMS indicates high sulfur levels, which may be responsible for loss of lead as a sulfate precipitate; however, this has not been confirmed.

TABLE A-17. SELECTED FORTIFICATION RECOVERIES FROM AQUEOUS CONDENSATE SAMPLE BY SSMS

Element	Total weight observed[a/] µg	Sample background weight observed[a/] µg	Fortification weight recovered[a/] µg	Fortification weight added µg	Recovery[b/] %
Sb	100	1.25	98.8	200	49
As	775	40	735	200	370
Cd	105	< 1.25	∿ 104	200	52
Cr	8,250	4,750	3,500	2,000	180
Cu	1,520	700	825	200	410[c/]
Fe	77,500	45,000	32,500	10,000	320[c/]
Pb	300	450	0	200	0
Ni	7,000	2,050	4,950	2,000	250
Zn	1,500	800	700	200	350[c/]

a/ The results are reported in three significant figures for calculation purposes only; the results are good to only two significant figures.

b/ $\text{Recovery} = \frac{\text{Fortification Weight Recovered}}{\text{Fortification Weight Added}} \times 100\%.$

c/ Unreliable recovery data due to sample concentrations excessively larger than the fortification concentrations.

TABLE A-18. SELECTED FORTIFICATION RECOVERIES FROM HYDROGEN PEROXIDE IMPINGER SAMPLE BY SSMS

Element	Total weight observed[a/] µg	Sample background weight observed[a/] µg	Fortification weight recovered[a/] µg	Fortification weight added µg	Recovery[b/] %
Sb	135	1.25	134	200	67
As	198	8.75	189	200	95
Cd	67.5	1.25	66	200	33
Cr	5,750	7,750	0	2,000	0[c/]
Cu	3,250	1,780	1,470	200	740[c/]
Fe	20,000	30,000	0	10,000	0[c/]
Pb	425	425	0	200	0
Ni	2,750	1,200	1,550	2,000	78
Zn	1,020	1,100	0	200	0[c/]

a/ The results are reported in three significant figures for calculation purposes only; the results are good to only two significant figures.

b/ $\text{Recovery} = \frac{\text{Fortification Weight Recovered}}{\text{Fortification Weight Added}} \times 100\ \%.$

c/ Unreliable recovery data due to sample concentrations excessively larger than the fortification concentrations.

TABLE A-19. FORTIFIED XAD RESIN QUALITY ASSURANCE DATA FOR SELECTED ELEMENTS BY SSMS ANALYSIS

Element	Original[a/] fortification (μg)	Recovered[b/] fortification (μg)	Recovery[c/] (%)
Antimony	100	8.4	8.4
Arsenic	100	29	29
Cadmium	100	2.3	2.3
Chromium	100	65	65
Copper	100	7.2	7.2
Iron	100	53	53
Lead	100	8.4	8 4
Tin	100	8.9	8.9
Zinc	100	11	11

a/ All selected elements were added as 100 μl aliquots of 1,000 μg/ml atomic absorption standard solutions.

b/ The resin-liquid slurry was dried prior to O_2 bomb treatment.

c/ $\text{Recovery} = \frac{\text{Recovered Fortification}}{\text{Original Fortification}} \times 100\%$

Recoveries of metal fortifications from samples of XAD-2 resin are generally low and variable. Low recoveries may be the result of volatilization losses during oxygen bomb operation. This case would be likely for Sb, As, Cd, Pb, Sn, and Zn. Recoveries of Cr and Fe, which are less volatile elements appear to be within the SSMS range of analytical precision. The poor recovery of copper is currently unexplained.

Problems

The most serious problems were observed in the recovery of sample fortifications from the liquid matrices. Although most of this difficulty is attributable to the addition of insufficient fortification quantities, the consistently low recovery of lead fortifications has not been definitively resolved. Additional problems encountered in the recovery of selected materials from reference materials has been generally attributed to operation at the extreme upper limit of the quantitative analysis range.

PROXIMATE ANALYSIS METHODS

Samples

The refuse material after removal of glass and metal components underwent proximate analysis. One refuse sample for each of the three test days was analyzed. A blind duplicate sample for one test was also analyzed.

Sample Preparation

The refuse collected for each test day was approximately 20 ft^3 of inhomogeneous material. The refuse was separated into glass, metal, and "other" fractions. The "other" fraction was weighed as received, and dried at $5^{o}C$ above ambient temperature until constant weight was reached. The total sample was then coarse ground before a smaller representative sample was taken. The representative sample was then further ground until it passed a No. 60 sieve.

Analysis Methods

Modified ASTM procedures were used for the analysis of refuse. The modification is simply applying analysis to refuse sample rather than coal. ASTM Method D-3172 was used which included: moisture determination by Method D-3173; ash by Method D-3174; volatile matter by Method D-3175; and fixed carbon by difference. Heat of combustion was also determined using a calorimeter as per ASTM Method D-271. All of these analyses were performed by Industrial Testing Laboratory, Kansas City, Missouri.

Quality Assurance

Analytical precision was monitored by submitting a blind duplicate of refuse sample for one test run.

The data for duplicate analyses for both proximate and ultimate tests are presented in Table A-20. All results are within $\pm$ 4% of the averaged values for duplicate tests with the exception of the sulfur analyses which fall into a $\pm$ 20% range. The larger error in the sulfur analyses may be due to the low levels analyzed and/or nonhomogeneous distribution of sulfur in refuse.

Problems

The main problem with these analyses is that of obtaining a representative sample of refuse and suitably preparing that sample for analysis. The procedure as used was devised by MRI and Industrial Testing Laboratory to assure that a representative sample was prepared for analysis.

TABLE A-20. PROXIMATE AND ULTIMATE BLIND DUPLICATE ANALYSIS OF REFUSE

Analysis	Run 2A	Run 2B	Relative deviation (%)
As received:			
Moisture	7.51	7.58%	0.5
Ash	3.93	4.20	3.3
Volatile matter	75.29	75.51	0.1
Fixed carbon	13.27	12.71	2.2
Sulfur	0.33	0.22	20
Heat of combustion	6,384	6,548 BTU/lb	1.3
Dry basis:			
Ash	4.25	4.55%	3.4
Volatile matter	81.40	81.70	0.2
Fixed carbon	14.35	13.75	2.1
Sulfur	0.35	0.24	19
Heat of combustion	6,903	7,085 BTU/lb	1.3
Hydrogen	6.01	6.08%	0.6
Carbon	47.61	46.76	0.9
Nitrogen	0.34	0.32	3.0
Oxygen	41.90	42.04	0.2

ULTIMATE ANALYSIS METHODS

Ultimate analysis was performed on refuse material after removal of glass and metal components. One sample for each of these test days was analyzed. A blind duplicate sample for one test day was also analyzed.

Sample Preparation

The sample preparation for ultimate analysis was identical to that used for proximate analysis.

Analysis Methods

Modified ASTM procedures were used for the analysis of refuse. The modification is simply applying the method to refuse rather than coal for which the method was written. ASTM Method D-3176 was used which included: determination of carbon and hydrogen by Method D-3178; sulfur determination by Method D-3177; nitrogen determination by Method D-3179; ash is the same as determined in proximate analysis; and oxygen is determined by difference.

Quality Assurance

Analytical precision was monitored by submitting a blind duplicate of refuse sample for one test run. The quality assurance data are included with the proximate testing quality assurance data, and are found in Table A-20.

Problems

The main problem encountered in these analyses is that of obtaining a representative refuse sample and suitably preparing that sample for analysis.

ANION ANALYSIS METHODS

Samples

Samples of ESP ash were analyzed for fluoride, chloride, bromide, cyanide, nitrate, and sulfate after either oxygen bomb decomposition or water leaching. Outlet gas samples for anion analysis consisted of aliquots taken from the potassium hydroxide impinger of the mercury train. These were analyzed for fluoride, chloride, bromide, and cyanide. All samples for anion analysis were liquid.

Sample Preparation

General Methods--

The sample preparation for each anion type from each sample type is sufficiently different to require individual description. The oxygen bomb preparation of ESP ash for halide analysis was done by Industrial Testing Laboratory.

Specific Methods--

Chloride--Samples which were obtained from the oxygen bomb decomposition of ESP ash were neutralized to pH 6 to 7 with concentrated nitric acid and the solutions diluted to 100 ml. Similar neutralization of the KOH impinger solutions to pH 6 to 7 was performed. All solutions were subsequently adjusted to a constant ionic strength. KOH samples were adjusted to 0.41 M $NaNO_3$, and oxygen bomb solutions of NaOH were adjusted to 0.20 M $NaNO_3$.

Bromide--Bromide sample preparation is identical to that used for chloride.

Fluoride--The same neutralized solutions as used for chloride and bromide were used for fluoride analysis except for the final ionic strength adjustment. Samples for fluoride were mixed 1:1 (v/v) with total ionic strength adjusting buffer (TISAB Orion 94-09-09A) just prior to analysis.

Cyanide--The ESP ash samples were prepared by soxhlet extraction of 20 g of ESP ash with water for 24 hr. During the extraction step, the boiling flask was kept basic by the addition of NaOH to prevent loss of cyanide. Analysis of fortified ESP ash samples indicated the necessity for a cyanide distillation step. Consequently, all ESP ash extracts were subsequently prepared including the distillation step. Analysis of residual materials in the distillation flask was not possible since acidic conditions were necessary to redissolve the residual material after completion of the distillation.

Sulfate--The leachate water used for cyanide was also used for sulfate. The leachate samples were passed through a 3 in. x 3/8 in. Rexyn 101 CH^+ column before analysis. Additional sulfate analyses were performed on residue which was removed from the distillation flask with hydrochloric acid. Approximately 50% of the sample sulfate content was found in the residue material.

Nitrate--The leachate water used for cyanide was also used for nitrate analysis. Analysis of residual material was inconclusive due to chloride ion interferences in the analytical method, which were introduced during dissolution of the deposits.

General Analysis Methods

Fluoride, chloride, bromide, and cyanide were measured by direct potentiometry using the ion selective electrode and reference electrodes listed in

Table A-21. All measurements were made using an Orion Model 701A digital ion-analyzer. Calibration curves were plotted on semilog paper and samples measured against these calibration curves. Calibration curves for both water and neutralized base systems were prepared for fluoride, chloride, and bromide.

Sulfate and nitrate were analyzed according to EPA Reference Methods 6 and 7, respectively. These are the methods as revised and found in the Federal Register (Thursday, August 18, 1977).

Quality Assurance

The quality assurance procedures used for anion analysis consisted of the following: all samples of each matrix type were analyzed in duplicate for each anion; solid samples were fortified with the anions of interest before sample preparation; one sample of each matrix type was analyzed by three-point standard addition method; and blanks (field and laboratory) were analyzed for the anion of interest. The quality assurance data for anions are summarized in Table A-22.

Problems

Many of anions were below detection limits in many of the samples. Analysis procedures with more sensitivity would be required for these samples. The use of the KOH impinger from the mercury train for the collection of chloride, fluoride, bromide, and cyanide should be reevaluated for the following reasons. The high concentration of KOH forces the ionic strength of the solution to be quite high for ion selective electrode measurements. A lower concentration of KOH may be possible. The low gas sampling rate and short sampling time for mercury vapor collection results in a small total gas volume sampled; therefore, anion species are at or close to detection limits in the KOH impinger. A larger volume of gas needs to be sampled to collect sufficient material for more reliable analysis.

Improved but low cyanide recoveries from fortified ESP ash were found with the use of a distillation technique. The interference tests for oxidizing agents and sulfite were negative. Possible explanations could be the formation of metal cyanide complexes or decomposition of cyanide during the distillation. Better cyanide analysis procedures are required, however, to assure that correct determinations are made.

After water leaching of ESP ash, a precipitate which was observed in the boiling flask which was removed using concentrated hydrochloric acid. In subsequent analyses for sulfate and nitrate, approximately 50% of the sample sulfate content was found in the acid rinse. Improved methods are needed for multiple anion analysis.

TABLE A-21. ION SELECTIVE ELECTRODES AND REFERENCE ELECTRODES USED FOR ANION ANALYSIS

Anion measured	Ion selective electrode	Reference electrode
Chloride	Orion 96-17 Combination electrode	a/
Bromide	Orion 94-35	Orion 90-01
Fluoride	Orion 94-09	Orion 90-01
Cyanide	Orion 94-06	Orion 90-01

a/ Single electrode that contains ion selective and reference electrode.

TABLE A-22. QUALITY ASSURANCE DATA FOR MERCURY TRAIN ANION ANALYSES

Anion	Sample detection limit		Standard additions comparison			Precision
	μg/ml	μg[a]	Direct analysis (μg)	Standard additions analysis (μg)	Accuracy[b] (%)	Relative standard deviation (%)[d]
Fluoride	0.20	40	53.3	81.4	66	17
Chloride	8.9	1,800	4,880	4,680	104	26
Bromide	0.56	110	125	116	108	2.5[e]
Cyanide	0.16	32	< 35	< 35	-[c]	-[c]

a/ Based on a total solution volume of 200 ml.

b/ $\text{Accuracy} = \frac{\text{Direct Analysis}}{\text{Standard Additions Analysis}} \times 100\%.$

c/ All samples at or below the detection limit precluding precision and accuracy calculations.

d/ Based on two measurements of duplicate samples.

e/ Based on two measurements of a single sample.

TABLE A-23. QUALITY ASSURANCE DATA FOR ESP ASH ANION ANALYSIS

Anion	Sample detection limit		Standard additions comparison			Precision	Fortified sample			
	μg/ml	μg	Direct analysis (μg/g)	Standard additions analysis (μg/g)	Accuracy (%)[a/]	Relative standard deviation (%)	Analyte background (μg)	Added fortification (μg)	Observed fortification (μg)	Recovery (%)[h/]
Bromide	0.42	42[f/]	850	1,200	68	12[b/]	210	110	93	84
Chloride	17	1,700[f/]	42,000	46,000	91	11[b/]	11,000	1,500	5,700	280
Cyanide	0.065	16[g/]	270[c/]	440[c/]	61[c/]	10[c,d/]	< 13	26,000	5,300	20
Fluoride	0.28	25[f/]	620	520	120	8.6[b/]	290	250	85	34
Nitrate	0.4	100[g/]	< 5	-	-	2.0[c/]	< 100	60,000	17,000	29
Sulfate	0.4	100[g/]	12,000	11,000	100	6.5[e/]	11,000	24,000	11,000	46

a/ Accuracy = $\frac{\text{Direct Analysis}}{\text{Standard Additions Analysis}} \times 100\%$

b/ Based on a minimum of four analyses.

c/ Based on a fortified sample.

d/ Based on duplicate analyses.

e/ Based on duplicate sample analyses.

f/ Based on 100 ml of solution after O_2 bomb decomposition.

g/ Based on 250 ml of extract solution.

h/ Recovery = $\frac{\text{Observed Fortification}}{\text{Added Fortification}} \times 100\%$

POLYCHLORINATED BIPHENYLS

Samples

Collector ash samples were specifically prepared and analyzed for PCB material. Methylene chloride extracts of size classified particulate, XAD-2 resin, aqueous condensate, and the organic module rinse from the SASS train were also analyzed for PCB. All collector ash samples were analyzed in duplicate.

Samples Preparation

General Methods--

Collector ash samples were extracted with hexane for subsequent PCB analyses. Aliquots of the SASS train sample extracts prepared for Level 1 organic analysis were used for the PCB analysis.

Specific Methods--

Twenty grams of each collector ash sample were mixed with pre-extracted anhydrous sodium sulfate to form a free-flowing mixture before extracting with 200 ml of hexane in soxhlet extractors for 8 hr. The hexane extracts were concentrated to 5 ml in Kuderna-Danish evaporators. Methylene chloride extracts from SASS train samples were solvent exchanged with hexane. One milliliter of methylene chloride extract was combined with 5 ml of hexane and evaporated to 1 ml. Five milliliters of hexane were again added and the sample was evaporated to 1 ml. Finally, the 1 ml was diluted to 2 ml with hexane. All extracts were partially cleaned by shaking with 5 ml concentrated sulfuric acid and 5 ml of 10% KOH in methanol.

PCBs were derivatized to decachlorobiphenyl (DCB) by perchlorination using $SbCl_5$. One-fourth of each extract was transferred to a clean culture tube (13 mm x 100 mm) with a TFE-lined cap and evaporated just to dryness under a stream of dry nitrogen. Antimony pentachloride (0.2 ml) was added, and the tube placed in an aluminum heating block at 160°C for 2 hr. After allowing the reaction mixture to cool to room temperature, the reaction was quenched by adding 2 ml of 50% HCl. Each mixture was then extracted four times with ~ 1-ml portions of hexane, and the extract dried by passage through a disposable pipette column of anhydrous sodium sulfate.

Analysis Method

All extracts were screened on a Varian 1400 GC using an electron capture detector. The column (1.8 m x 2 mm I.D.), which was a glass tube packed with 3% SP-2401 on 100/120 mesh Supelcoport, was operated isothermally at 190°C with a nitrogen flow of 30 ml/min. The extracts were screened against an Arochlor 1254 standard at the 1 ng/μl level. All extracts exhibited several peaks within the Arochlor 1254 retention time range, but no specifice Arochlor pattern was evident.

The derivatized samples were analyzed on the same column, but the temperature was held isothermally at 250°C.

GC/MS was used to confirm the presence of PCB residues in the underivatized portions of selected extracts. The extracts were concentrated to 5.0 ml by evaporation under a gentle stream of dry nitrogen prior to examination for di-, tri, tetra-, and pentachlorobiphenyls. The GC/MS system utilized was a Varian/MAT 311-A interfaced with a Varian 2700 via a two-stage Watson-Bieman separator. The MS, controlled by a Varian 620/i MS data system, was sequentially focused on m/e 222, 224, 256, 258, 290, 294, 324, and 326. The GC column, as described for screening, was held isothermally at 180°C and was eluted with helium at a flowrate of 30 ml/min. PCBs were identified by coincident peaks in the two plots for a particular chlorobiphenyl with the characteristic relative intensities. The sensitivity of the system was extablished by assaying an Aroclor 1254 standard.

Quality Assurance

Quantitative analysis of PCB was made using the DCB analysis. Table A-24 presents the quality assurance data for collector ash fortified with Arochlor 1254. An average recovery of 154% of DCB was found for the perchlorination of Arochlor 1254 fortified collector ash. All collector ash samples were prepared in duplicate; however, all responses were at or below the instrumental detection limit, precluding precision calculations.

Filter, XAD-2 resin, and solvent blanks were analyzed in all phases of analysis to identify potential contamination sources.

Problems

Direct analysis of both collector ash and SASS train extracts by EC/GC produce a number of extremely low intensity peaks which could not be correlated to the Arochlor 1254 standard. The derivatization of the sample extract to DCB resulted in a complex mixture producing a positive response at the retention time corresponding to DCB. Subsequent analysis of underivatized sample extracts failed to confirm the presence of PCB materials in any samples except the XAD-2 resin field sample.

TABLE A-24. PCB ANALYSIS QUALITY ASSURANCE DATA[a/]

Sample	Total observed DCB content (ng)	Sample DCB content (ng)	DCB fortification	Recovery (%)
125A	290	21	160	168
125B	245	21	160	140

a/ As determined by EC-GC analysis of sample aliquots derivatized to DCB. Fortifications of Arochlor 1254 were employed.

POLYNUCLEAR AROMATIC HYDROCARBONS

Samples

Samples of ESP ash and particulate, XAD-2 resin, aqueous condensate, and organic module rinse from the SASS train were analyzed for polynuclear aromatic hydrocarbons (PAH). An ESP ash sample from each test day was analyzed. A duplicate sample for one run, a fortified sample, and reagent blanks were analyzed for quality assurance.

Sample Preparation

General Methods--

Collector ash samples were specifically prepared for PAH analysis as described below. The SASS train samples were extracted for Level 1 organic analysis and will be only briefly described in this section. More detail on sample preparations for Level 1 are given later in this appendix.

Specific Methods--

Twenty grams of each collector ash sample were mixed with pre-extracted anhydrous sodium sulfate to form a free-flowing mixture prior to extraction with 200 ml of hexane in soxhlet extractors for 8 hr. The soxhlet extractors were wrapped with alumninum foil to protect the samples from light. The sample extracts were subsequently concentrated to a volume of 5 ml with aluminum-wrapped Kuderna-Danish evaporators. All samples were stored in the dark at $4^{o}C$ prior to analysis. Prior to GC/MS analysis, the samples were fortified with D_{10}-anthracene as an internal standard.

Samples generated from the SASS train were analyzed directly after the first concentration step in the Level 1 analysis scheme. The sample aliquots were also fortified with the D_{10}-anthracene internal standard.

Sample Analysis

General Methods--

Samples were analyzed by GC/MS using a capillary column. Identification and quantification of specific PAH compounds were made based on retention times and extracted ion plots characteristic of the compounds. The specific procedures are given in the following section.

Specific Methods--

The chromatographic conditions used for the capillary column analysis of PAH are given in Table A-25. A reconstructed ion chromatogram (RIC) of the 14-component standard is presented in Figure A-1. As illustrated, two clustered peaks are produced by more than one compound. With enhanced selective ion monitoring, it was found that chromatographic resolution was achieved for phenanthrene and anthracene at scan 524 and 531, respectively, as shown in

TABLE A-25. GC/MS OPERATING CONDITIONS FOR PAH ANALYSIS

Capillary column

Column: 30 m SE-30 WCOT
Column temperature: Initial hold 150°C for 4 min, program rate 8°C/min to 280°C
Instrument: Finnigan 4000
Injection mode: Splitless
Column pressure: 15 psi
Scan rate: 1.2 sec/mass decade
Scan range: 40 to 400 amu
Ionization potential: 70 eV
Emission current: 0.2 ma
Multiplier voltage: 1,650 v

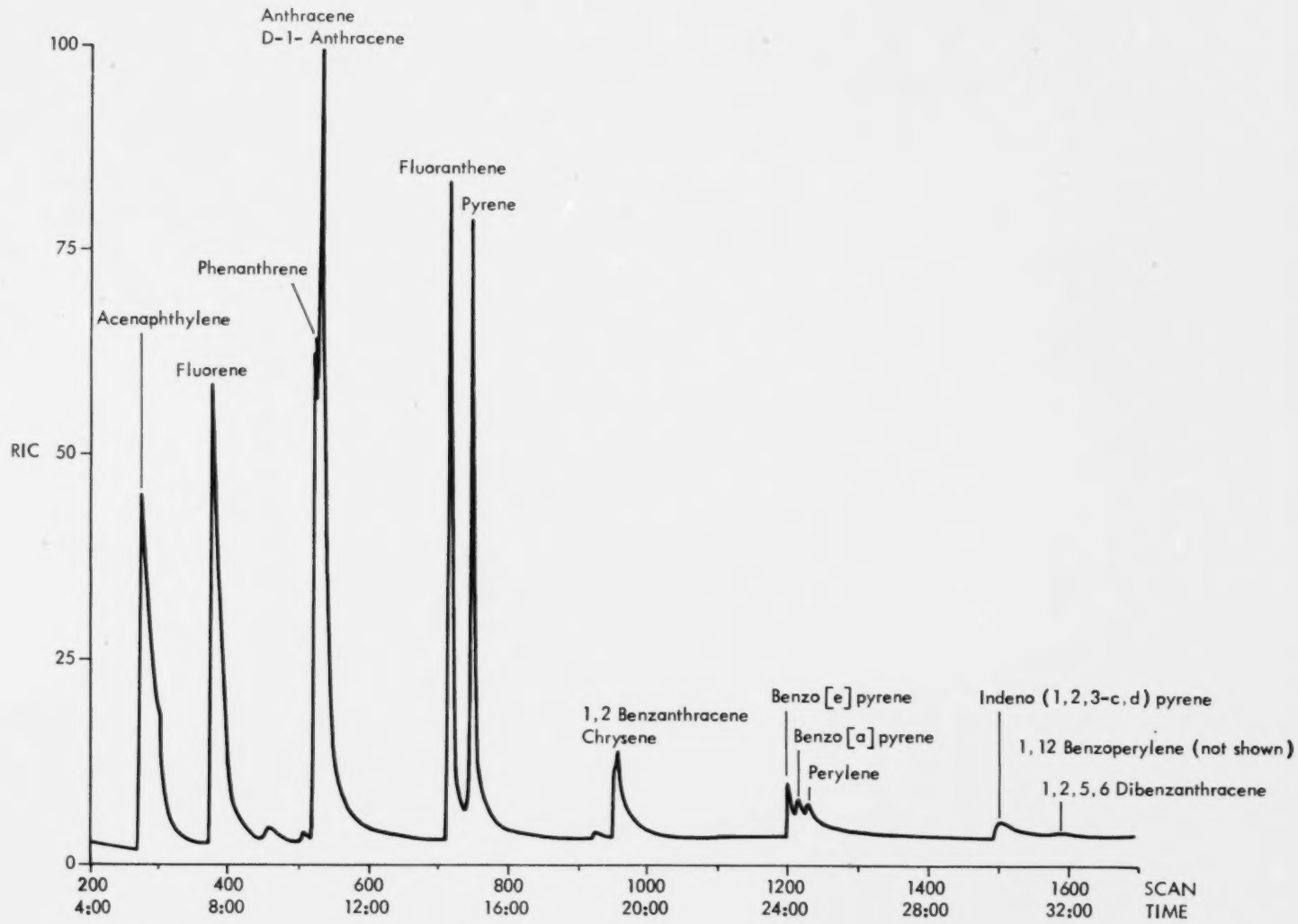


Figure A-1. Reconstructed ion chromatogram (RIC) of the PAH standard.

Figure A-2. Although anthracene and D_{10}-anthracene were not clearly resolved chromatographically, mass resolution was accomplished for ions at M/e 178 and 188, respectively. Similarly, the cluster at scan 959 produced by 1,2-benzanthracene and chrysene was resolved as illustrated in Figure A-3. An identifiable response from 1,2,5,6-dibenzanthracene was not observed, which has been attributed to its low solubility in the standard solution.

The RIC for a collector ash extract is shown in Figure A-4 and is generally indicative of the sample complexity. Extracted ion plots were made using the three ions of highest intensity characteristic for each of the PAH compounds. Identifications were based on the presence of the three ions maximized at the correct retention time and with the correct ratio of intensities. Figure A-5 illustrates the positive identification of pyrene in the XAD-2 resin extract. Concentrations were determined from the integrated peak areas. Peak area was subsequently converted to concentration values using instrumental response factors based on analyses of standards.

Quality Assurance

Collector ash samples were prepared in duplicate for determination of analytical precision. Fortified samples of collector ash and a fortified hexane solvent blank were prepared and carried through the soxhlet extraction to monitor extraction efficiency. Solvent, XAD-2 resin, and filter blanks were prepared and analyzed. All samples were protected from heat and light.

Prior to analysis the MS was calibrated with perfluorokerosene. Standards at two levels were analyzed during sample analysis.

Quality assurance recoveries for fortified samples, as shown in Table A-26, were found to vary from one PAH to another. Difficulty in the recovery of the PAH materials from the collector ash shown in Table A-27 may be the result of several effects: the inability of hexane to extract PAH from the collector ash in a soxhlet extractor or enhanced PAH decomposition because of possible occlusion of PAH from solvent contact due to the hydrophobic nature of solvent due to contact with the particulate (catalytic decomposition, adsorption, or increased heat transfer promoting increased decomposition).

Problems

The chemical problems observed in the recovery of PAH fortifications from sample and solvent materials may involve either inability to extract the analytes efficiently, or decomposition of analytes during the sample preparation.

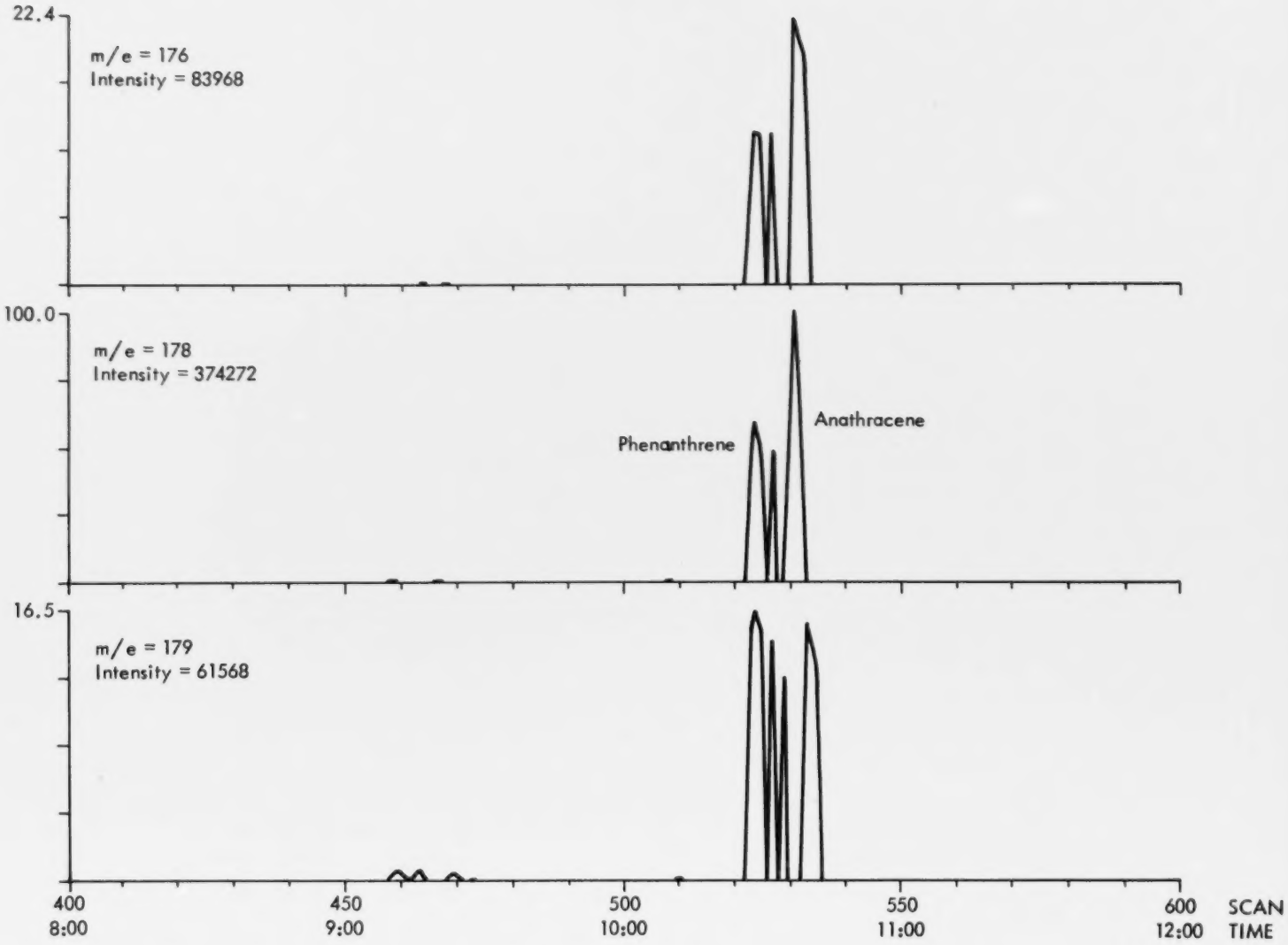


Figure A-2. Ion plot for M/e 176, 178, and 179 (phenanthrene and anthracene) for PAH standard.

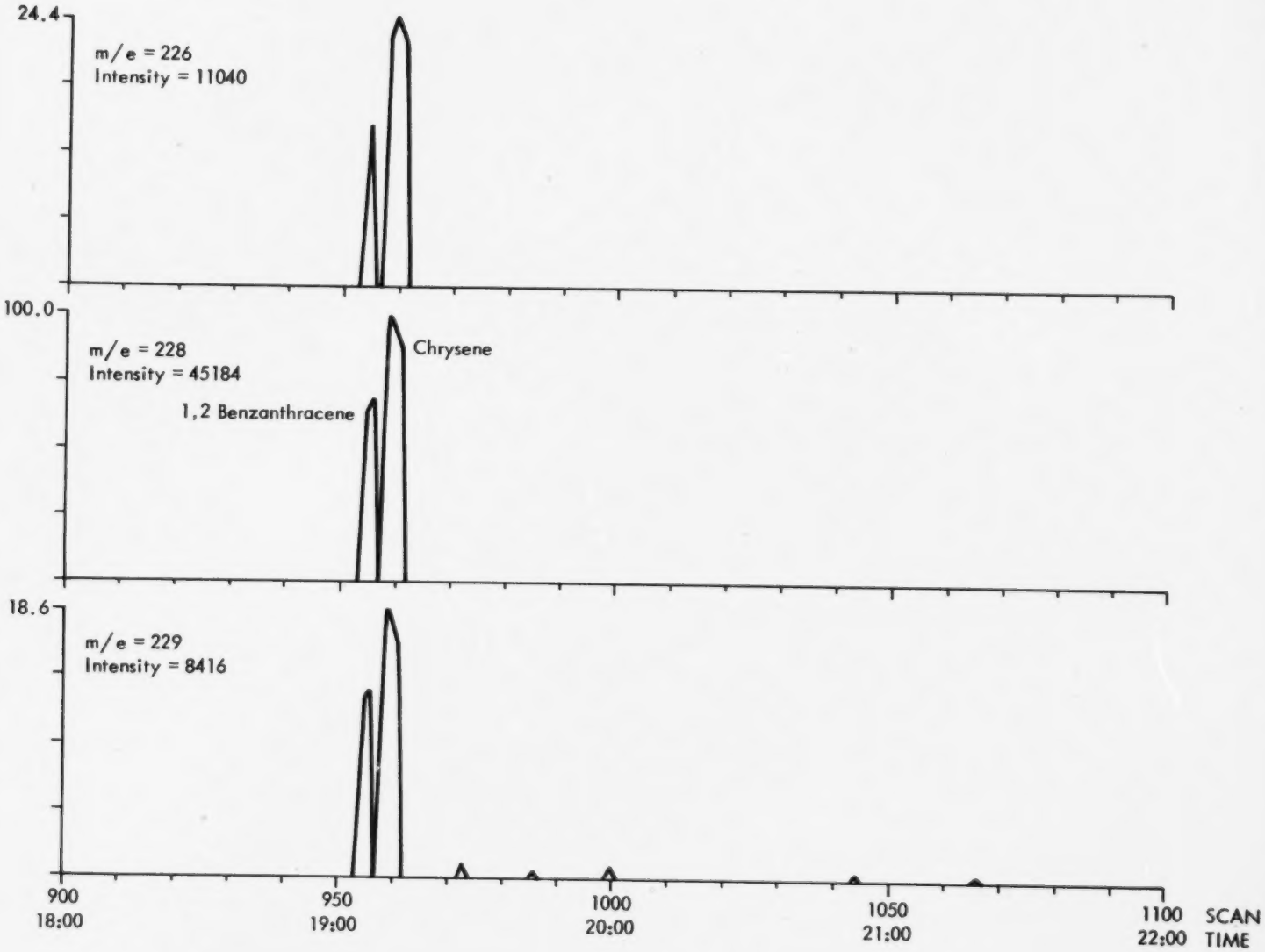


Figure A-3. Ion plot for M/e 226, 228, and 229 (1,2 benzanthracene and chrysene) for PAH standard.

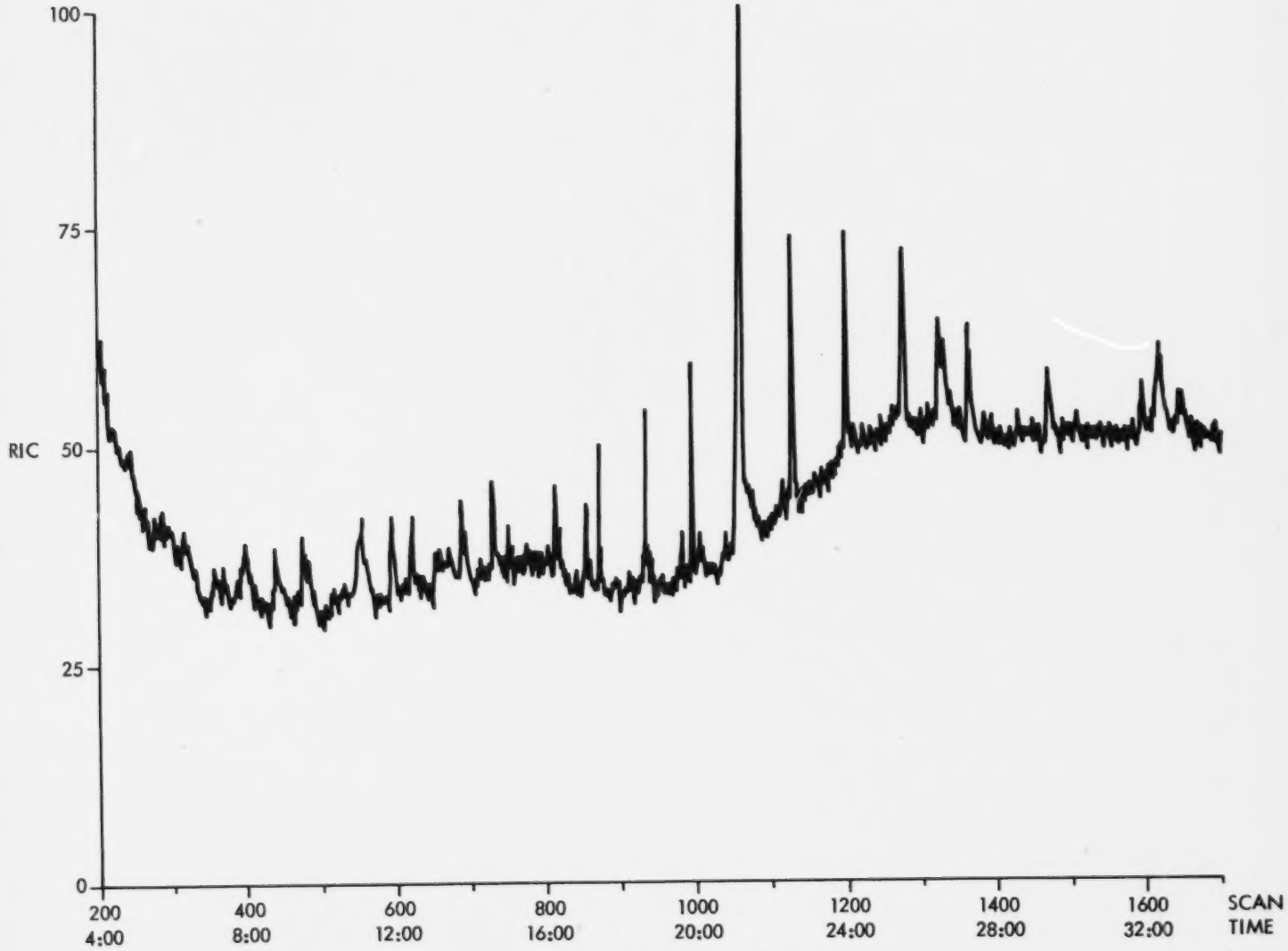


Figure A-4. Reconstructed ion chromatogram (RIC) for collector ash extract.

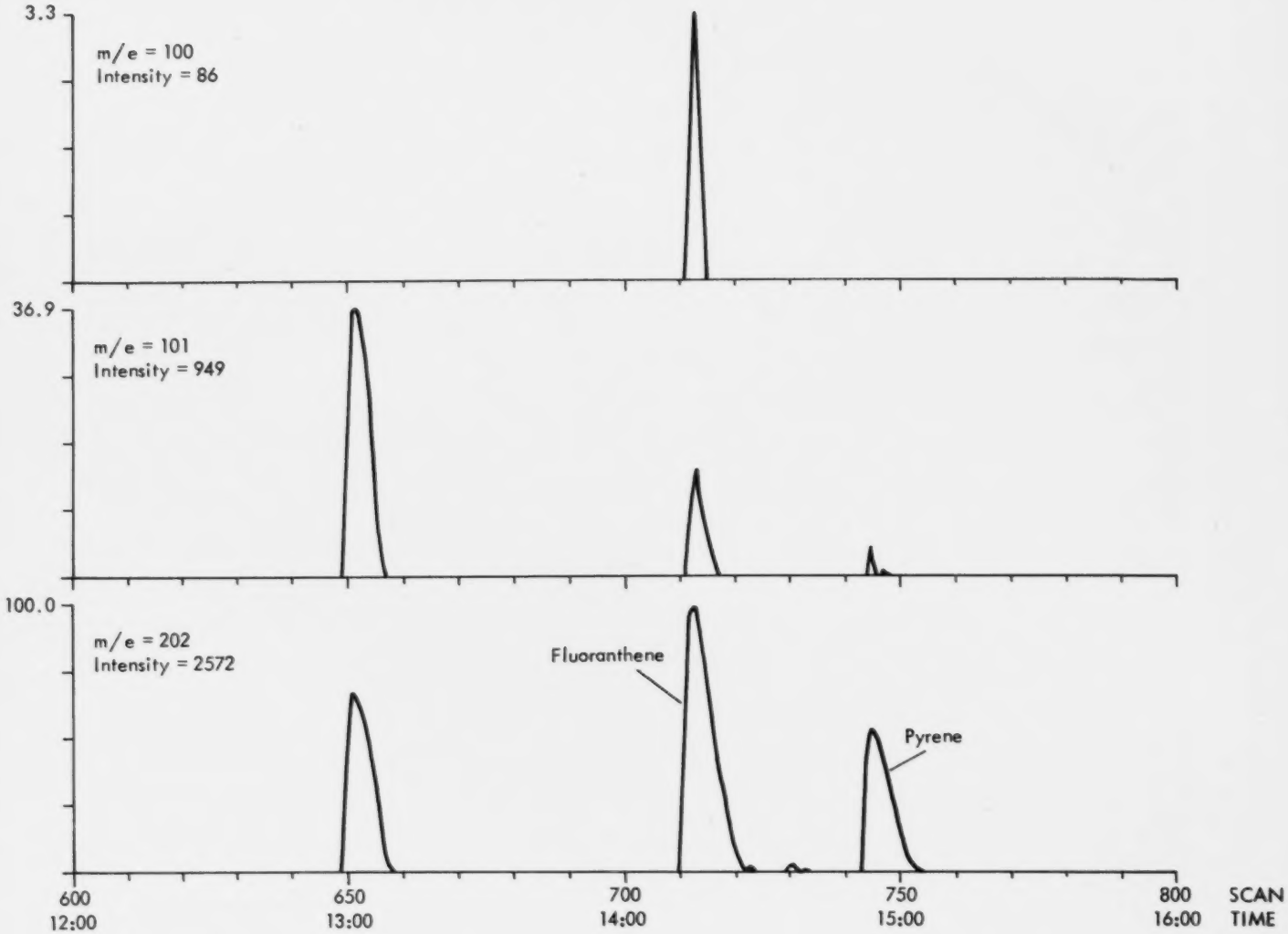


Figure A-5. Ion plot for pyrene in XAD-2 resin extract.

TABLE A-26. RECOVERIES OF PAH FORTIFICATIONS FROM HEATED HEXANE[a/]

Compound	Observed quantity (μg)	Added quantity (μg)	Recovery (%)
Acenaphthylene	264	508	52
Fluorene	264	531	50
Phenanthrene	242	502	48
Anthracene	363	499	73
Fluoranthene	273	538	51
Pyrene	153	499	31
1,2-Benzanthracene	517	386	134
Chrysene	696	506	138
Benzo[e]pyrene	NA[b/]	NA	NA
Benzo[a]pyrene	934	475	197
Perylene	NA	NA	NA
Indeno(1,2,3-C,D)pyrene	4,820	1,020	474
1,12-Benzoperylene	NR[c/]	182	NR
1,2,5,6-Dibenzanthracene	NR	161	NR

a/ This hexane was soxhlet extracted for 8 hr.

b/ Not added during fortification.

c/ Not reported due to insufficient standard concentration for reliable response factor calculation.

TABLE A-27. RECOVERIES OF PAH FORTIFICATIONS FROM ESP ASH

Compound	Observed quantity (μg)	Added quantity (μg)	Recovery[a/] (%)
Acenaphthylene	177	508	35
Fluorene	170	531	32
Phenanthrene	90	502	18
Anthracene	95	499	19
Fluoranthene	216	538	40
Pyrene	125	499	25
1,2-Benzanthracene	ND[b/]	286	0
Chrysene	ND	506	0
Benzo[e]pyrene	ND	NA[c/]	-
Benzo[a]pyrene	ND	475	0
Perylene	ND	NA[c/]	-
Indeno(1,2,3-C,D)pyrene	ND	1,017	0
1,12-Benzoperylene	ND	182	0
1,2,5,6-Dibenzanthracene	ND	1 1	0

a/ $\text{Recovery} = \frac{\text{Observed Quantity}}{\text{Added Quantity}} \times 100\%$

b/ Not detected at the instrumental detection limit.

c/ Not added during sample fortification.

Data analysis was complicated by the nonlinear relationship between the response factor and PAH concentration. Since the response factor in this analysis is compound and concentration dependent, accurate sample concentration calculations require the use of response factors based on standards of comparable concentrations. This situation mandates the use of more closely matched standard and sample concentrations for high accuracy analysis. Finally, the use of D_{10}-anthracene as an internal standard was not possible due to the low final concentrations of the D_{10}-anthracene fortifications employed.

Since PAH sample concentrations were found at levels at or below the analytical detection limits, precision calculations could not be made.

LEVEL 1 ANALYSIS METHODS

Samples

Level 1 environmental assessment methods for gases (containing particulates) were included in the test program. Samples of the outlet gas stream were collected using SASS during the second test day. Bioassays were not performed on any samples. Organic and inorganic analyses were performed on all SASS train samples including particulates, XAD-2 resin, and aqueous condensate. These analyses were performed according to the method contained in "IERL-RTP Procedures Manual, Level 1 Environmental Assessment" (EPA-600/2-76-160); and included any revisions available at the time of sample analysis. Additional inorganic analyses were performed on the impinger solutions. Only selected inorganic gas analyses were performed on site, and no organic GC analyses for C_1 through C_6 compounds were performed on site. Continuous on-site analyses of the following gases were performed: O_2, NO_x, SO_2, hydrocarbons, CO_2, and CO.

The organic Level 1 analysis protocol is unique to Level 1 and is not covered in other sections of this appendix. Therefore, only organic Level 1 analyses will be discussed in this section.

Sample Preparation

General Methods--

Sample preparation methods used were those defined in EPA-600/2-76-160a, a draft revision of Chapter 8 received November 22, 1977, and subsequent applicable revisions, which were received May 31, 1978. Samples were extracted with methylene chloride, aliquoted, and concentrated to a volume of 10 ml using Kuderna-Danish evaporators. A sample aliquot which contained an amount of TCO material between 10 and 100 mg was either evaporated to dryness or solvent-exchanged depending on its TCO level. This sample aliquot was then liquid-chromatographed on silica gel and eight fractions were collected with subsequent analysis of the first seven fractions. The above sequence of sample preparation steps, and decision-making criteria, are schematically shown in Figure A-6. A summary of samples prepared and the analyses subsequently performed on them are presented in Table A-28.

Specific Methods--

Particulate samples were combined according to the Level 1 analysis scheme prior to extraction of organic material. The particulate samples were subsequently extracted with methylene chloride.

XAD-2 resin was prepared before use according to the procedure in the draft revision of Chapter 8 of the Level 1 document. The XAD-2 samples were soxhlet-extracted using <u>only</u> methylene chloride after testing, as specified in the draft revisions.

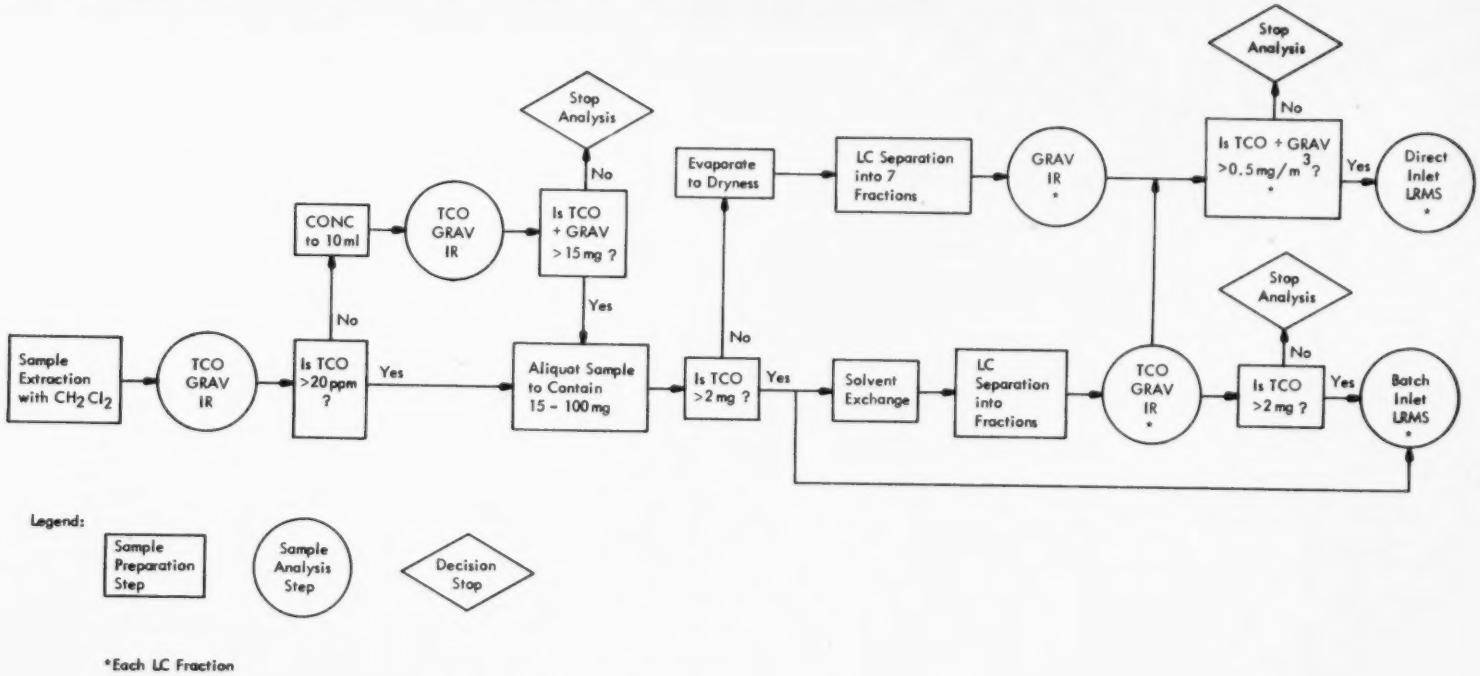


Figure A-6. Organic Level 1 analysis flow diagram.

TABLE A-28. LEVEL 1 ORGANIC ANALYSIS SAMPLE SUMMARY

Samples prepared	Preliminary analysis			Concentrate analysis			Analysis terminated	LRMS batch inlet analysis	Solvent exchange	LC fractionation	Analysis of all LC fractions			LRMS direct inlet analyses (fractions analyzed)
	TCO	GRAV	IR	TCO	GRAV	IR					TCO	GRAV	IR	
Combined 10 μ and 3 μ particulate	X	X	X	X	X	X	X							
Combined 1 μ and < 1 μ particulate	X	X	X	X	X	X	X							
XAD-2 resin field sample	X	X	X	X	X	X		X	X	X	X	X	X	LC5, LC6
Aqueous condensate extract	X	X	X	X	X	X		X	X	X	X	X	X	None
Organic module rinse	X	X	X	X	X	X	X							
Methylene chloride blank	X	X	X	X	X	X	a/		X	X	X	X	X	None
Methylene chloride/methanol blank	X	X	X	X	X	X	X							
XAD-2 resin blank	X	X	X	X	X	X	a/		X	X	X	X	X	LC5, LC6
Filter blank	X	X	X	X	X	X	X							

a/ Although the blank material did not qualify for continued analysis using Level 1 criteria, the appropriate blanks were carried through all extended analyses performed on corresponding samples.

Aqueous condensate was adjusted to pH 2 and 12, and extracted with methylene chloride at each pH. The extracts were then combined before analysis.

Sample Analysis

General Methods--

Organic Level 1 methods include GRAV, measurement of IR spectra, determination of TCO materials, and MS (direct inlet and batch inlet) procedures. Analytical methods for each procedure are discussed below.

Gravimetric determination was performed on all unconcentrated samples and sample liquid chromatographic (LC) fractions by evaporation of an aliquot (5 ml) of methylene chloride extract or LC solvent fraction. Gravimetric determinations of concentrated samples were made by evaporation of 1 ml aliquots.

IR spectra were obtained from the residues obtained from GRAV. The samples were prepared by dissolving the residue in a minimum amount of methylene chloride and transferring the solution to KBr plates. The methylene chloride was then evaporated and the IR spectra obtained for all samples. A Beckman IR 12 was used to obtain the IR spectra.

TCO analyses were performed useng a Varian 2400 GC with flame ionization detector. A glass column (1.83 m x 2 mm I.C.) packed with 1.5% OV-101 Gas Chrom Q., 100/120 mesh, was used. The temperature conditions were as follows: 4 min initial hold at 50°C; temperature programmed from 50 to 250°C at 20°C/min; injector temperature, 200°C; and detector temperature, 275°C. Chromatograms were recorded on an HP Model 3380A recording integrator. Sample volumes of 5 μl were used for all TCO analysis.

MS analyses were performed using a Varian/MAT CH-4 with a Varian 620/i data system. Thermograms from 50 to 460°C at approximately 50°C/min were performed on the direct inlet samples. Batch inlet samples were analyzed at 80°C. The MS operating conditions were the same for both techniques, as listed in Table A-29.

Specific Methods--

IR spectra obtained from concentrated XAD-2 extract, concentrated aqueous condensate extract, XAD-2 LC fraction 6, and aqeuous condensate LC fractions 6 and 7 consisted of absorbance peaks characteristic of a variety of different compound categories. The IR spectrum observed for the concentrated aqueous condensate extract is illustrated in Figure A-7. The major absorption peaks are generally characteristic of aliphatic and aromatic carbonyl-containing compounds. The low prevalence, or absence, of materials containing hydroxyl and/or carboxylic acid functional groups is suggested by the absence of intense broad-band absorption in the region of 3000-3400 cm^{-1}. These functional group assignments were typical of the IR data for samples producing interpretable IR spectra. Compound identification beyond the functional group assignments was not attempted due to the mixture complexity observed in TCO and LRMS analyses.

TABLE A-29. LRMS OPERATING CONDITIONS

Ionizing voltage	70 eV
Ionizing current	60 μa
Multiplier voltage	2.3 kV
Mass range	0-400 m/e
Scan rate	5 sec/mass decode

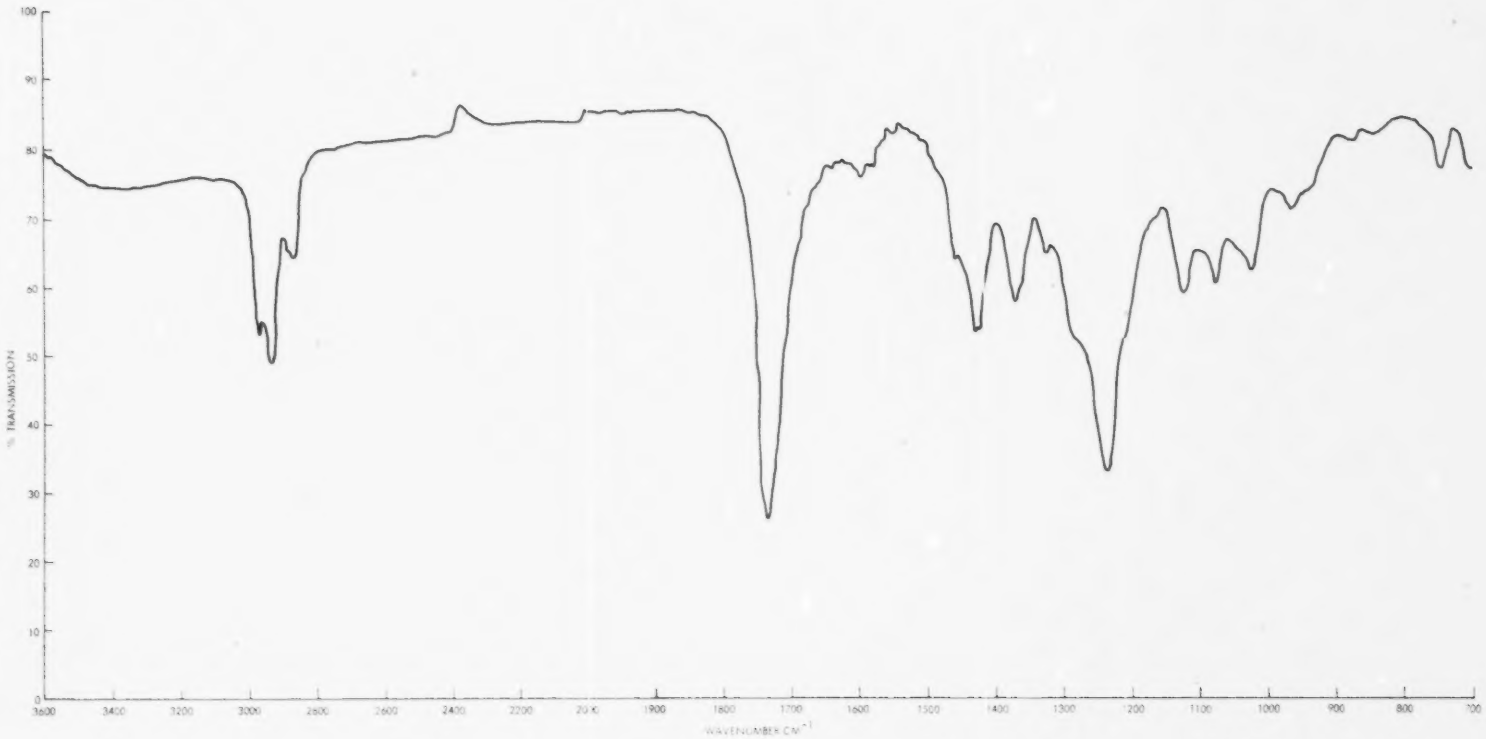


Figure A-7. IR spectrum of aqueous condensate extract before LC fractionation.

The TCO chromatogram for concentrated XAD-2 resin extract prior to LC fractionation is shown in Figure A-8, which depicts a complex mixture containing at least 40 components. Additional low concentration materials may be unobserved in the continuum of overlapping peaks. Only small quantities of chromatographable material after LC fractionation were observed in LC 1; however, numerous components are observed in LC fractions 2 to 6 (see Figure A-9). The amount of chromatographable material in LC fraction 7 was found to be very low. In this case only LC fractions 5 and 6 provided sufficient material to warrant LRMS analysis. Although the LC fractionation procedure has been found to provide some isolation of sample types, complex mixtures were observed even after LC fractionation.

The batch inlet MS of unfractionated XAD-2 resin extract is shown in Figure A-10, which is an extremely intense methylene chloride spectrum, and yields no useful sample data. Similar results were obtained from the batch inlet MS analysis of the unfractionated aqueous condensate sample. In an attempt to acquire additional information, an aliquot of the same extract was dried under a prepurified nitrogen stream and analyzed using the direct inlet system. The direct inlet MS of the dried, unfractionated XAD-2 extract is shown in Figure A-11, which yields considerably more observable ions than are found using batch inlet techniques.

The direct inlet thermogram for the XAD-2 resin extract LC fraction 6 is shown in Figure A-12. Three regions of increased ion intensity are observed corresponding to approximately 50°C, 150°C, and 300°C. Range plots were made to identify the location(s) of high molecular weight compounds shown in Figure A-13. The three regions of increased ion intensity are again observed, which are indicative of compounds having significantly different volatilities. It is also of note that more components appear to have masses less than 300 m/e. Additionally, compounds having masses greater than 300 m/e appear to be most prevalent in the intermediate temperature rante.

MS data were monitored for every 10 scans and compared. Subtle changes in the spectra were observed; however, the complexity of the sample mixture precludes detailed interpretation. Three spectra corresponding to the three temperature ranges of increase ion intensity are shown in Figures A-14 to A-16 The most notable changes are increased ions at m/e $>$ 250 in the intermediate range. The apparent clusters of more intense ions at 12 to 15 mass intervals suggests the presence of either a homologous series of compounds or fragmentation of an alkane-type high molecular weight compound.

In an attempt to derive some additional information from the direct inlet LRMS, the data were assembled in an alternate manner. A matrix of mass versus intensity was constructed for selected spectra after subtraction of the corresponding blank spectra. Peak intensitites at 14 mass intervals appear as the matrix columns. A column will have high intensities when homologous series are present. After a series is identified, a map can be consulted to identify possible compound classes which could produce the observed series.

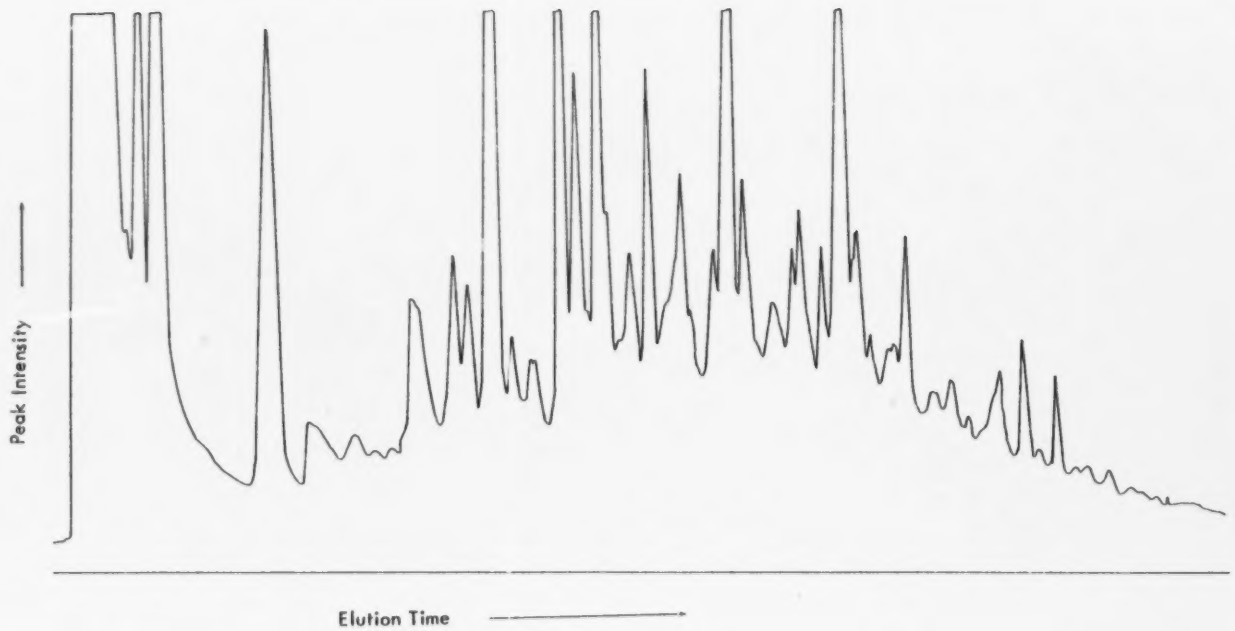


FIGURE A-8. TCO chromatogram for XAD-2 field sample concentrated extract before LC fractionation.

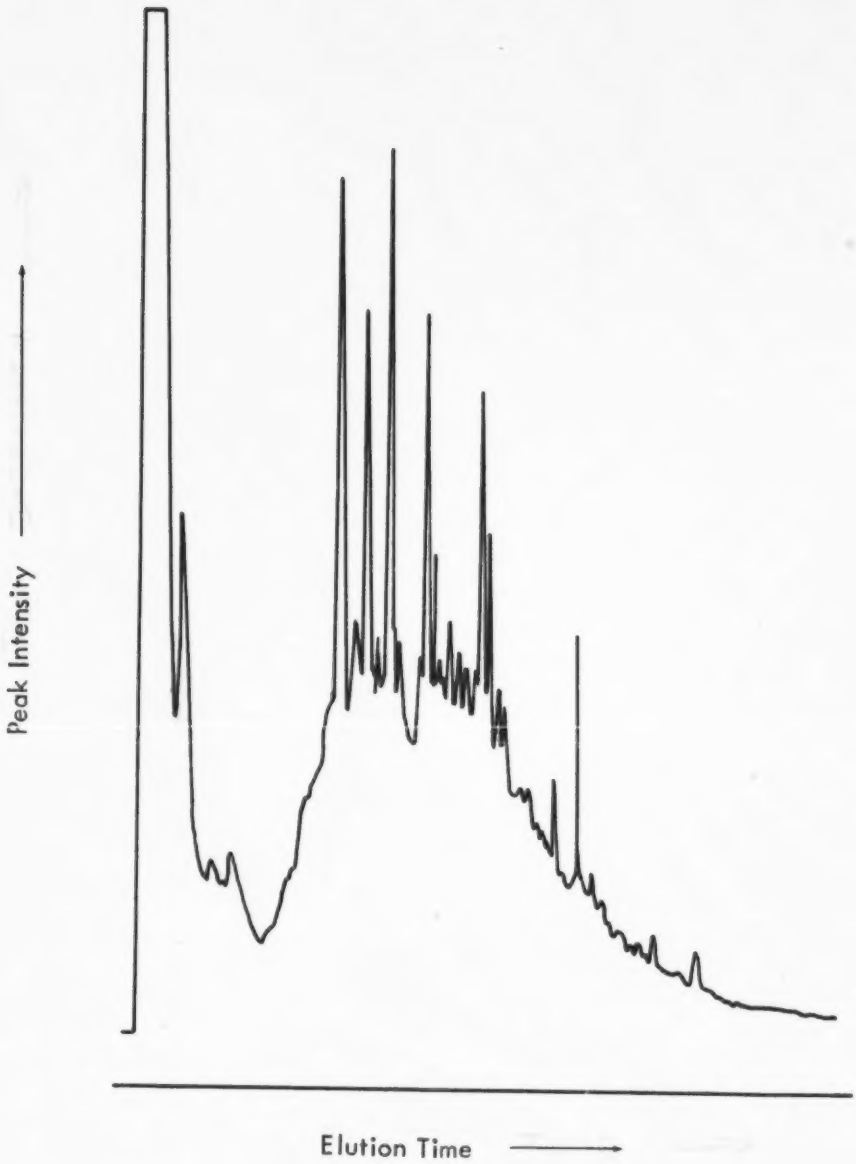


Figure A-9. TCO chromatogram for XAD-2 field sample LC fraction 6.

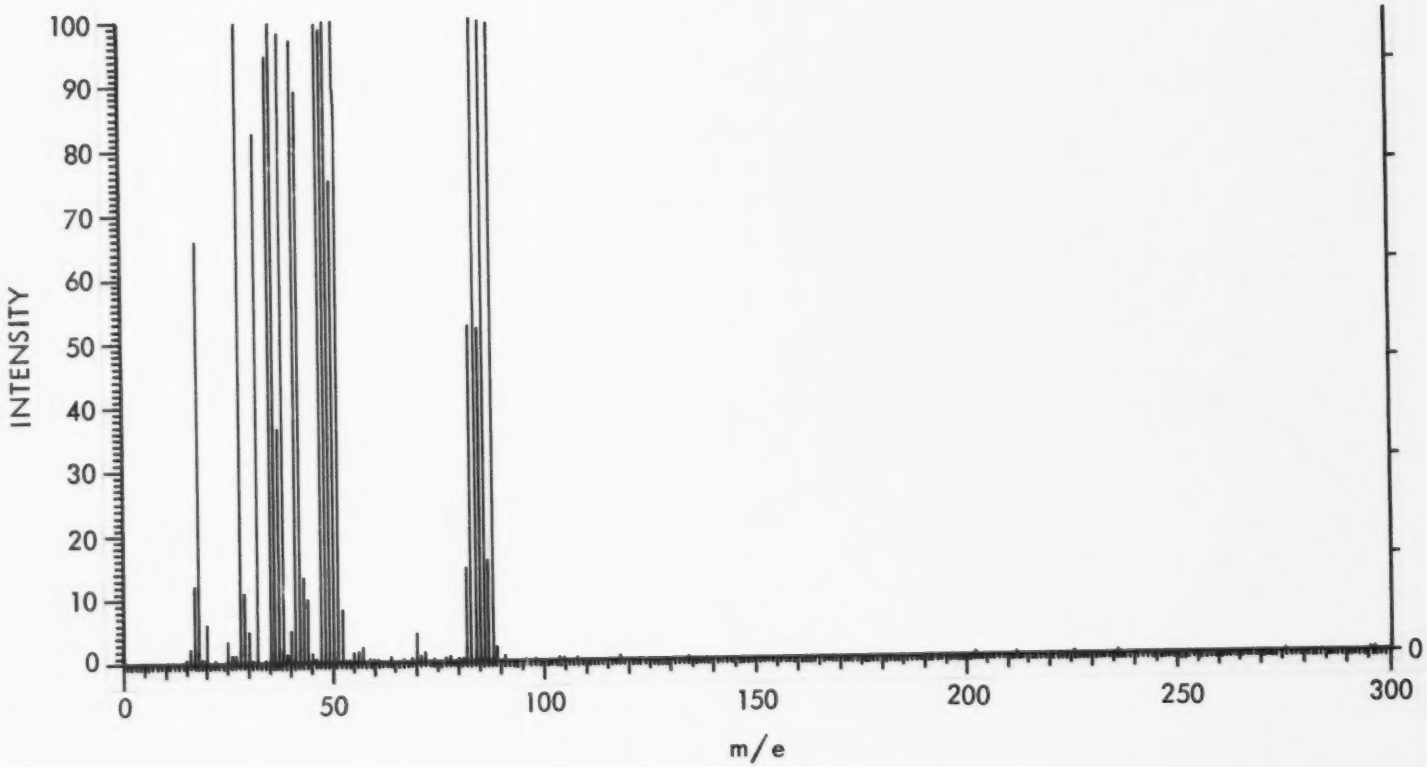


Figure A-10. Batch inlet MS of XAD-2 resin extract before LC fractionation.

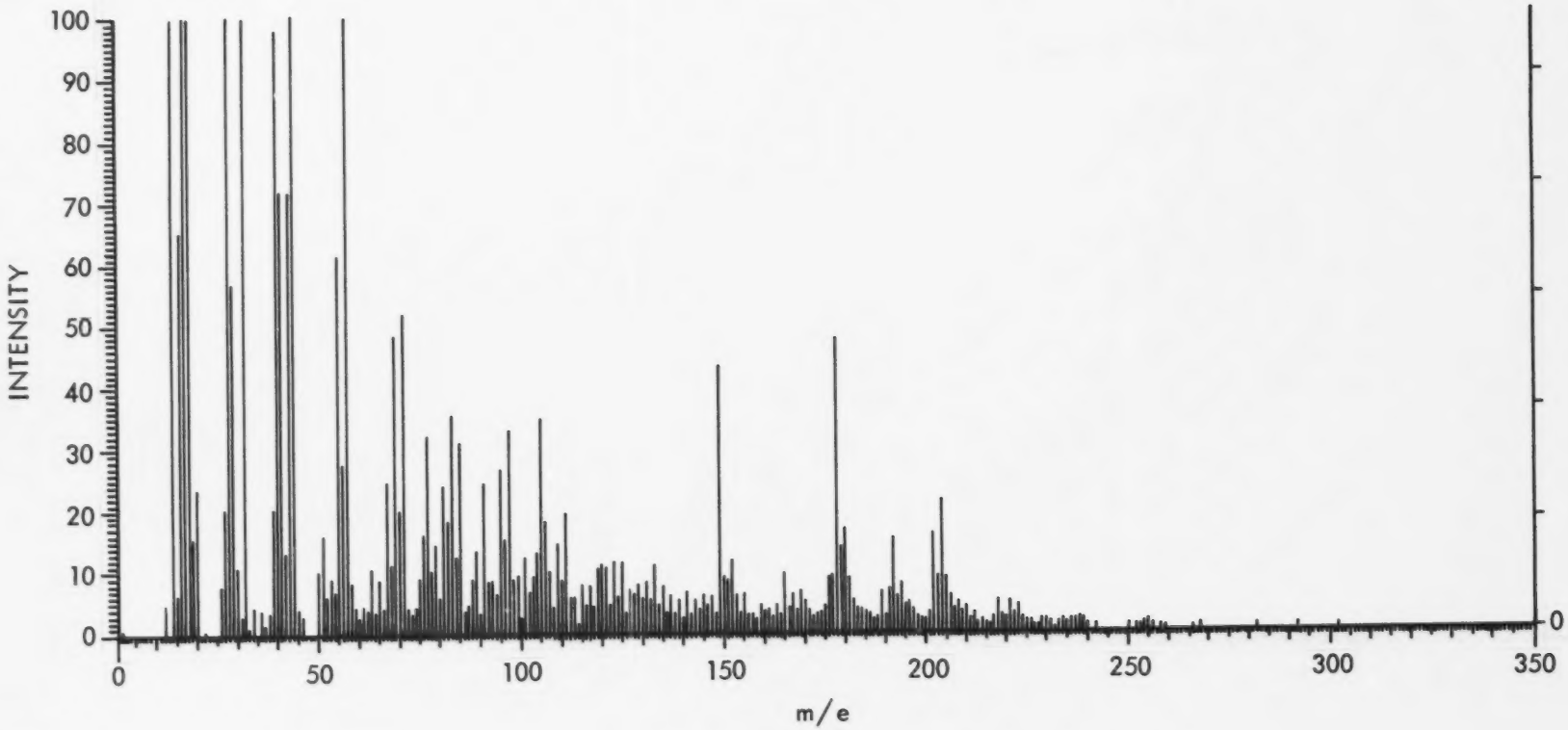


Figure A-11. Direct inlet MS of dried, unfractionated XAD-2 resin extract before LC fractionation.

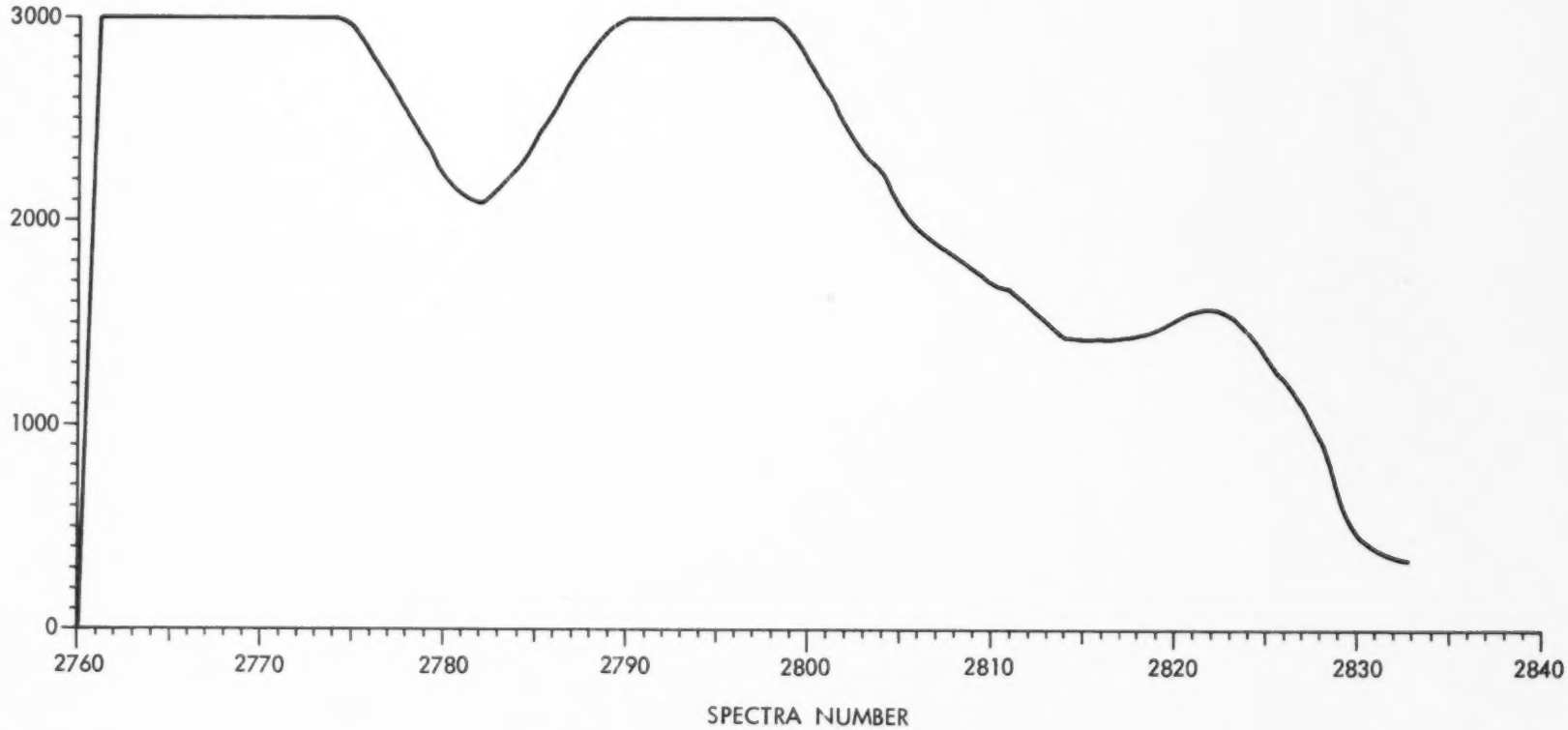


Figure A-12. Direct inlet thermogram for XAD-2 resin extract LC fraction 6.

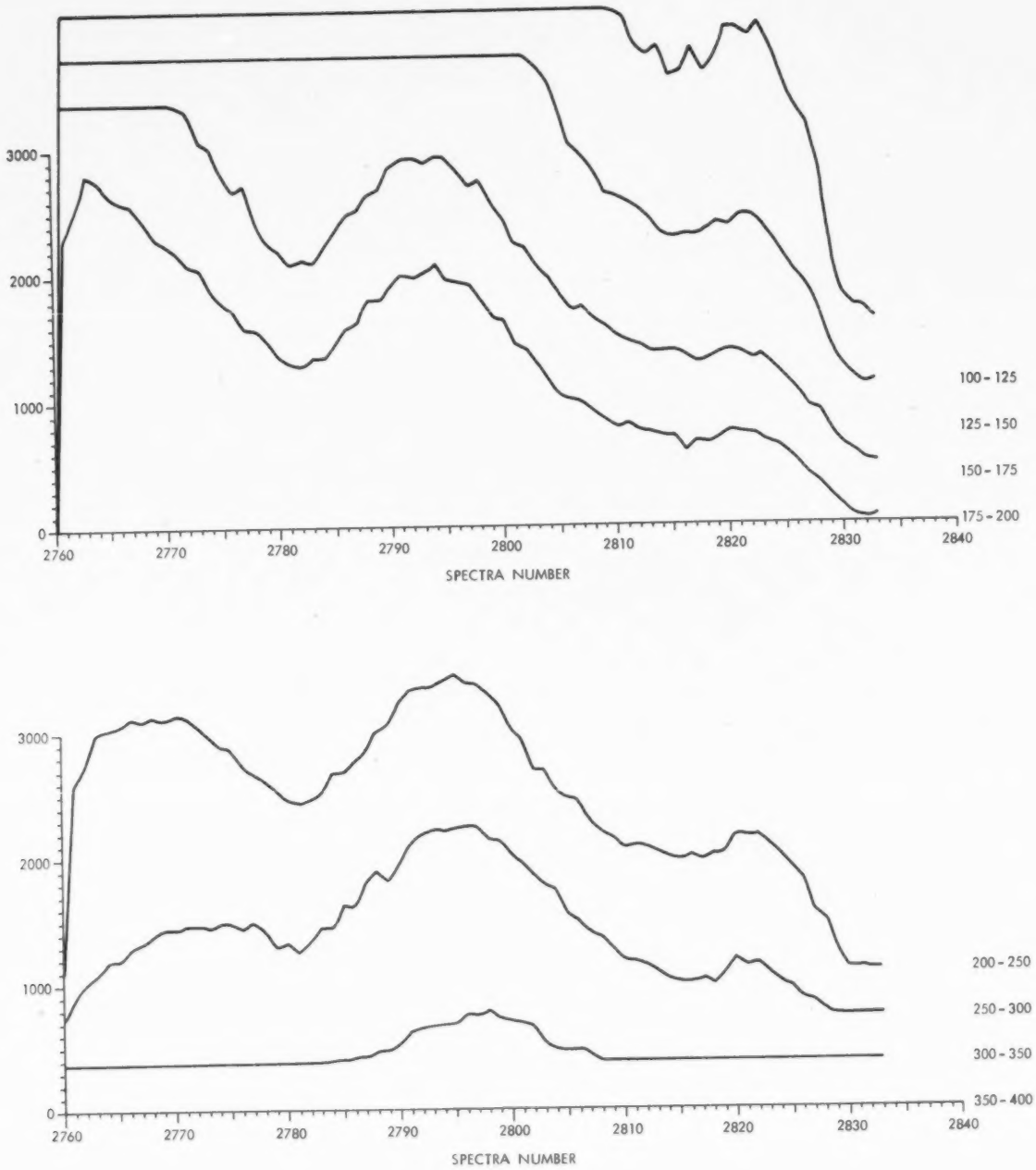


Figure A-13. Range plots for direct inlet MS of XAD-2 resin extract LC fraction 6.

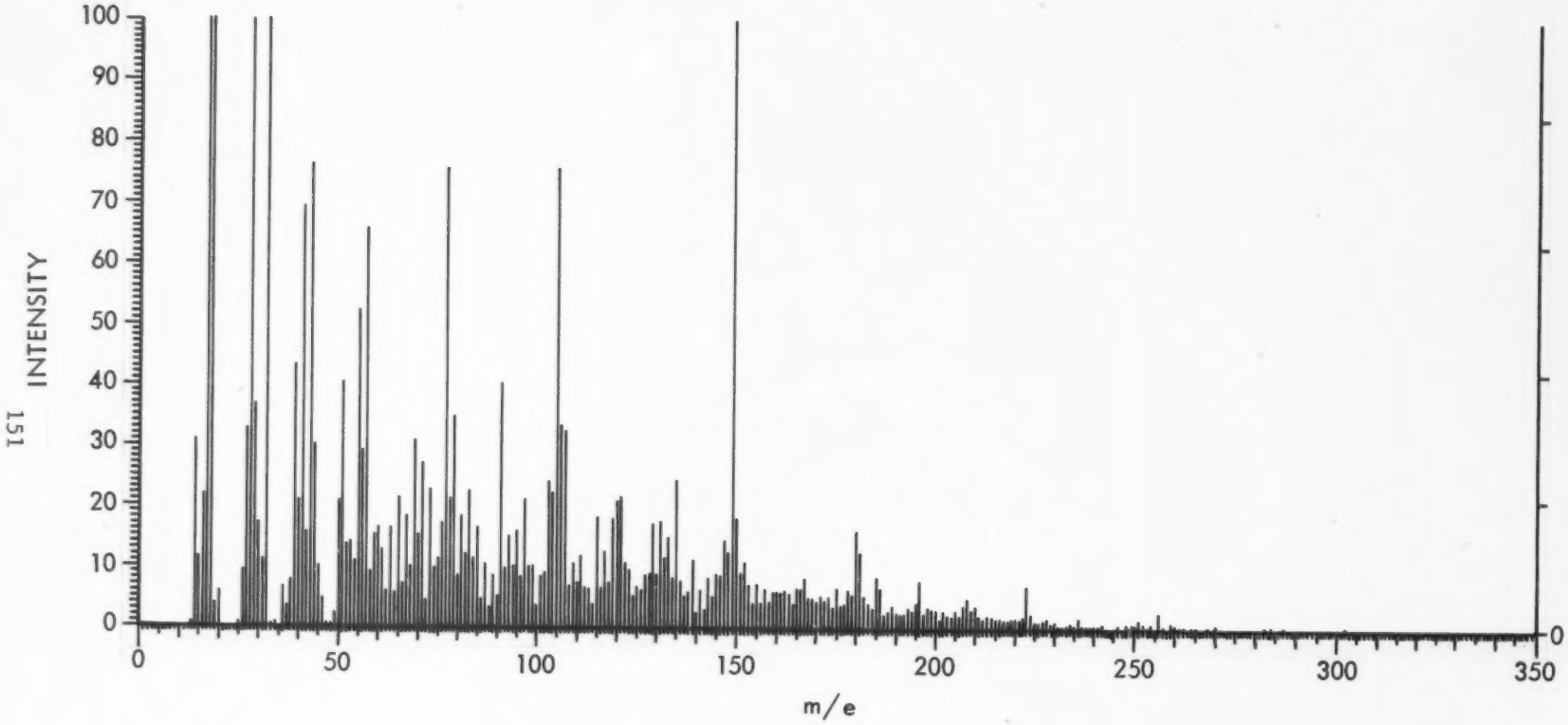


Figure A-14. Direct inlet MS of XAD-2 resin extract LC fraction 6 temperature ≈ 40°C.

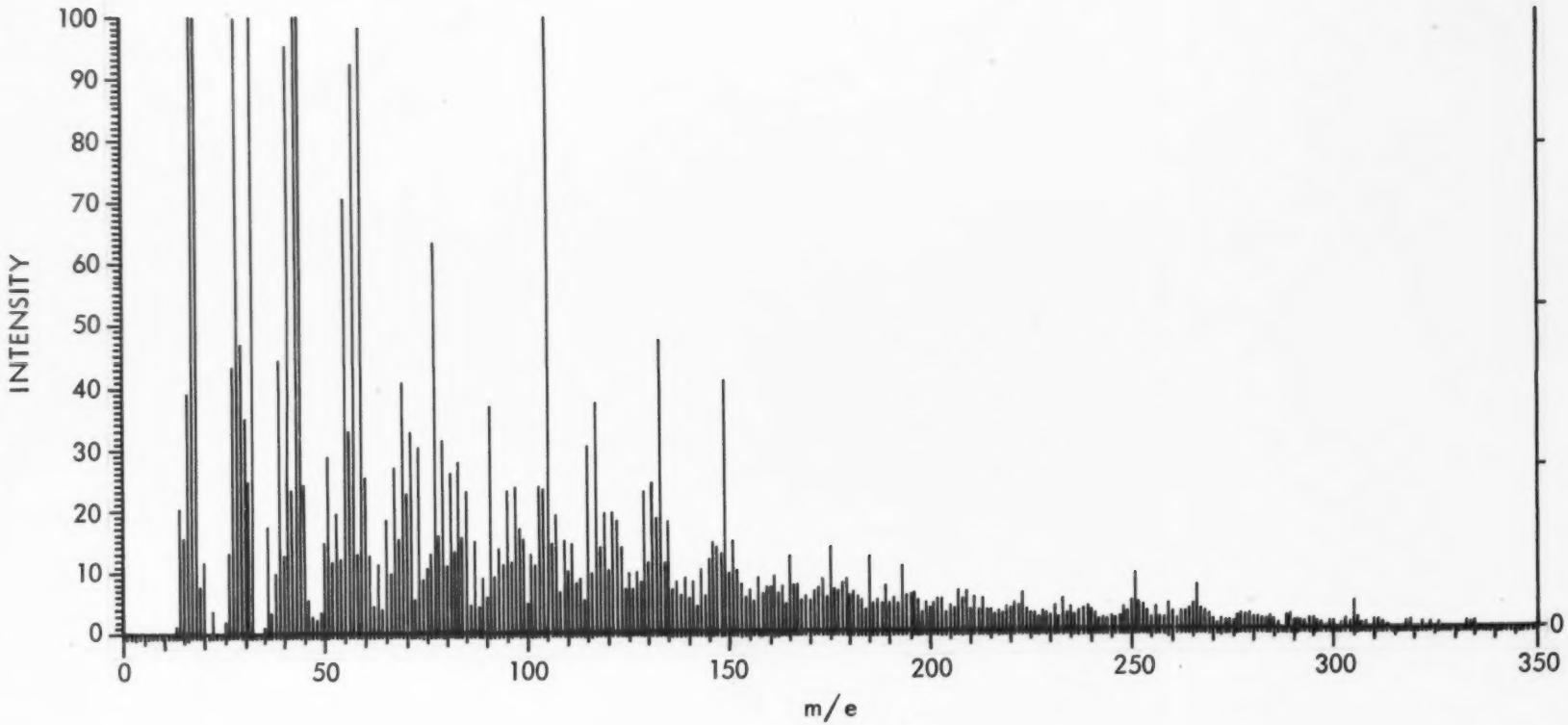


Figure A-15. Direct inlet MS of XAD-2 resin extract LC fraction 6 temperature ≈ 150°C.

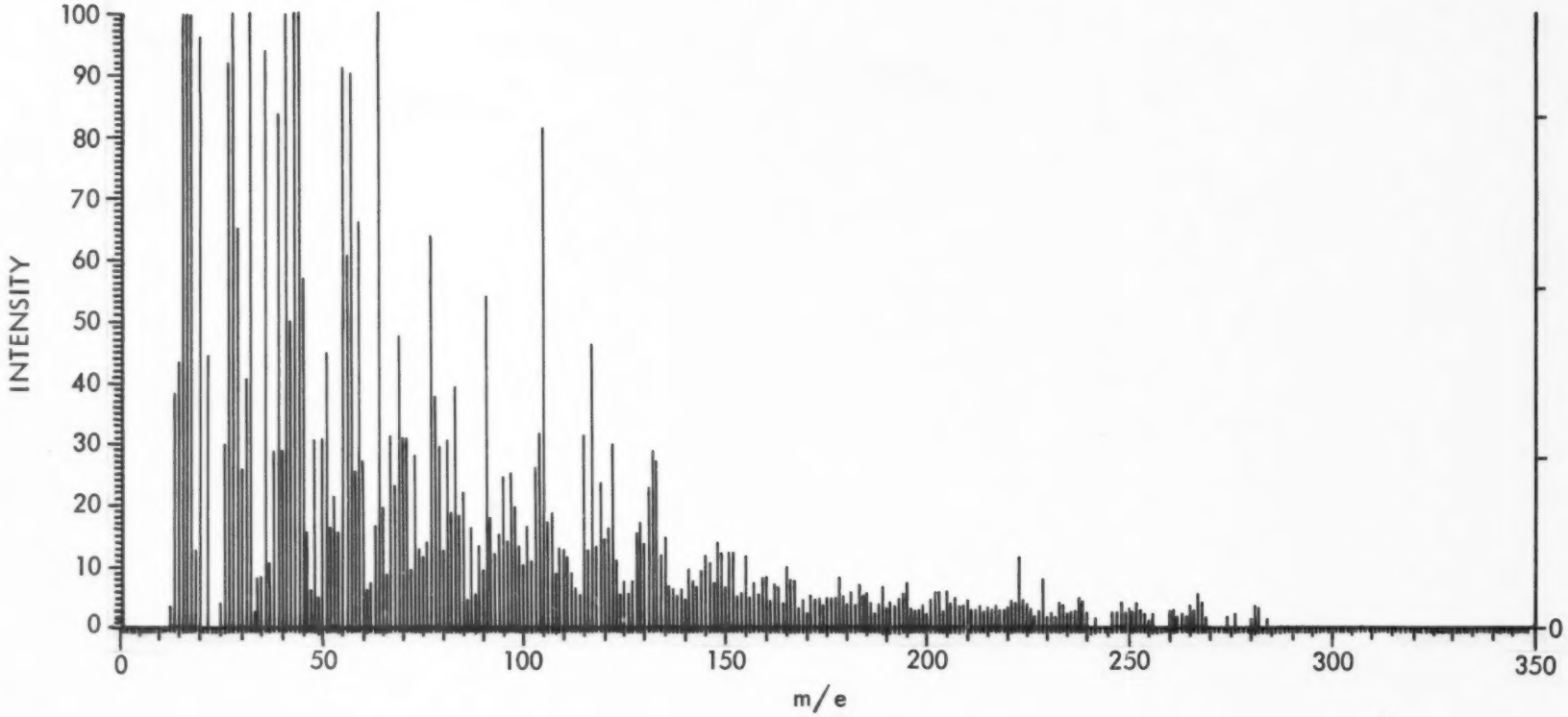


Figure A-16. Direct inlet MS of XAD-2 resin extract LC fraction 6 temperature ≈ 300°C.

The possible classes which would not be found in a given LC fraction were eliminated from consideration. The remaining classes are those possibly present in the sample. Listings of the possible compound classes at three different direct inlet temperatures were constructed. It must be noted that the success of this technique presumes the presence of homologous series of particular compound classes which may in fact not be the case.

QUALITY ASSURANCE

Quality control was carried out in accordance with those procedures specified in the draft revision for Level 1 organic analysis. Samples for quality assurance include those for calibration procedures and analysis of blanks. Specific procedures used are described below.

TCO analyses were made using commercially prepared standard mixtures containing C_6-C_{10} compounds and C_{10}-C_{18} compounds. Standards were chromatographed at the beginning and end of an analysis day, and intermittently with samples, to ensure no degradation occurred in column performance or detector response. The IR spectrophotometer was calibrated using polystyrene during each day of use. The MS was mass calibrated with perfluorokerosene before analysis. Calibration of the analytical balance was made using NBS-certified weights before proceeding with any gravimetric determinations.

Burdick and Jackson distilled in glass solvents (methanol, methylene chloride) were used to pre-extract the XAD-2 resin. All methylene chloride, used for XAD-2 and aqueous extractions, was obtained from the same lot. A blank of XAD-2 resin was prepared from the same lot and pre-extraction batch that was to be used in the SASS sampling runs. This was taken to the field and exposed to the field lab conditions as was the actual sample. This XAD-2 blank was carried through all Level 1 analysis procedures used for the XAD-2 used in the SASS run, including LC fractionation and LRMS analysis. A methylene chloride blank or greater equal to in volume to that used for particulate and/or aqueous extractions was prepared from the solvent lot used for all analyses. The methylene chloride blank was carried through all the Level 1 analysis procedures used for the samples through LC fractionation including TCO, GRAV, and IR analysis of LC fractions 1 through 7. A similar solvent blank was prepared from methylene chloride and methanol for the SASS train rinses of the front half and organic module.

Problems

Batch inlet MS of samples is of no value, due to the low relative concentration of any single compound in the multicomponent mixture compared to the amount of solvent entering the mass spectrometer. As a result, the MS is swamped with large quantities of solvent, which is the only detectable material observed in these analysis.

Direct inlet MS of complex samples as encountered in this program yielded little useful information with which to identify the types of organic compounds present. More structural characterization might have been possible if GC/MS data were obtained for the samples analyzed in this study. The cost would not be significantly higher when compared to the information that could be obtained. The fractionation on the LC column could be used to select GC columns for optimum chromatographic separation for GC/MS analysis of the samples as another method to increase the amount of characterization information from these types of samples.

Attempts to interpret data from the LC fractionation scheme were hampered by the incomplete specification of compound categories to be found in particular LC fractions.

APPENDIX B

SAMPLING LOCATIONS AND PROCEDURES

LOCATION OF SAMPLING POINTS

Samples for this project were drawn from one ESP inlet and three ESP outlet sampling locations (see Figure B-1). The inlet sampling points are located in the bypass duct between Units Nos. 1 and 2 (see Figures B-1, B-2, and B-4). The outlet sampling points are located upstream of the ID fan, in the stack 7 ft above the breeching and in the stack 35 ft above breeching (see Figures B-1 and B-3). The ducting configurations at the inlets to both ESP units were not suitable for sampling, therefore, only Unit No. 1 was fired and the flue gas was diverted to the ESP of Unit No. 2 through the existing bypass duct, which was utilized to draw the inlet samples.

Inlet Sampling Location

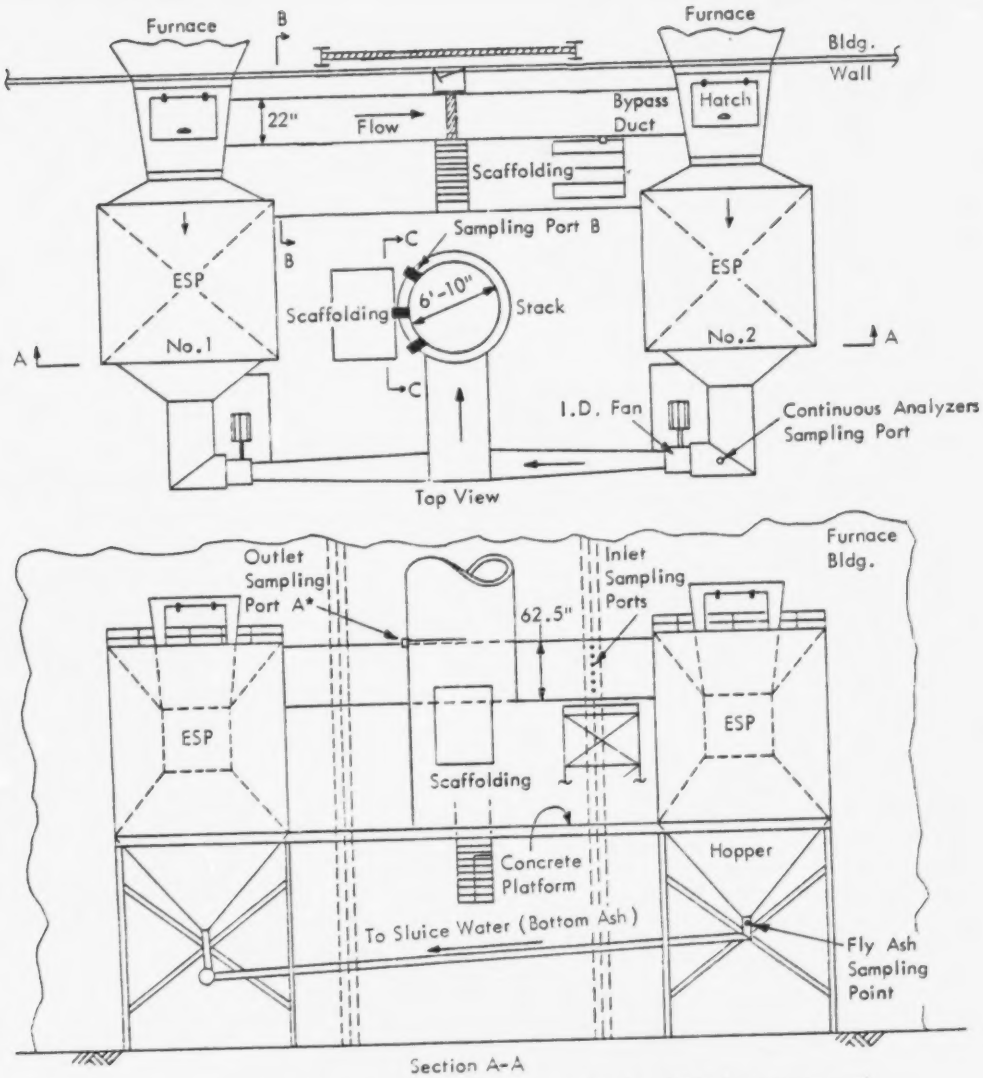
Figures B-1, B-2, and B-3 are schematic illustrations of the inlet sampling location. Six vertical sampling ports are located in a plane perpendicular to the flow and at a distance of 30 ft (>8 equivalent duct diameters) downstream and 6 ft (>2 equivalent duct diameters) upstream from any flow disturbances. Therefore, 12 traverse points were assigned to sample for particulate (EPA Method 5) from this duct. Figure B-4 is a dimensioned schematic illustration of the location of these points. The location of the Brink impactor sampling point is also shown in Figure B-4.

Outlet Sampling Locations

Three sampling locations were utilized to draw the required samples for the six sampling systems used to trap the pollutants in the stack emissions. These are shown in Figure B-5.

Continuous Monitoring System Sampling Location--

This system was located in a heated trailer on the ground level near the ESP hoppers. The system consisted of O_2, NO_x, SO_2, HC, and CO continuous monitors. The sampling interface of this system drew its sample from the ESP outlet just upstream of the ID fan (see Figure B-1).



*NOTE: Sampling Port A was used to draw samples for aldehyde, mercury and SASS trains.
Sampling Ports B were used to draw samples for Method 5 and particulate sizing trains.

Figure B-1. Schematic illustration of the plant's two units.

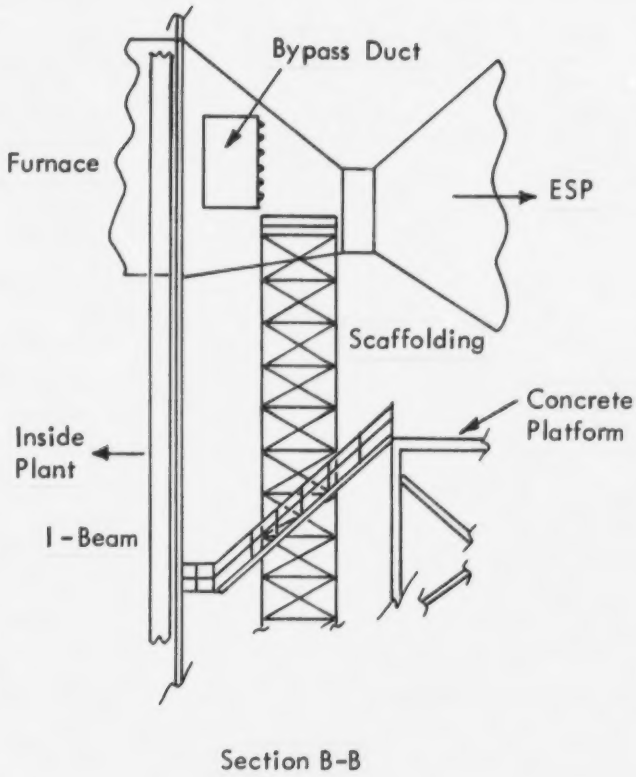


Figure B-2. Schematic illustration of Section B-B, Figure B-1.

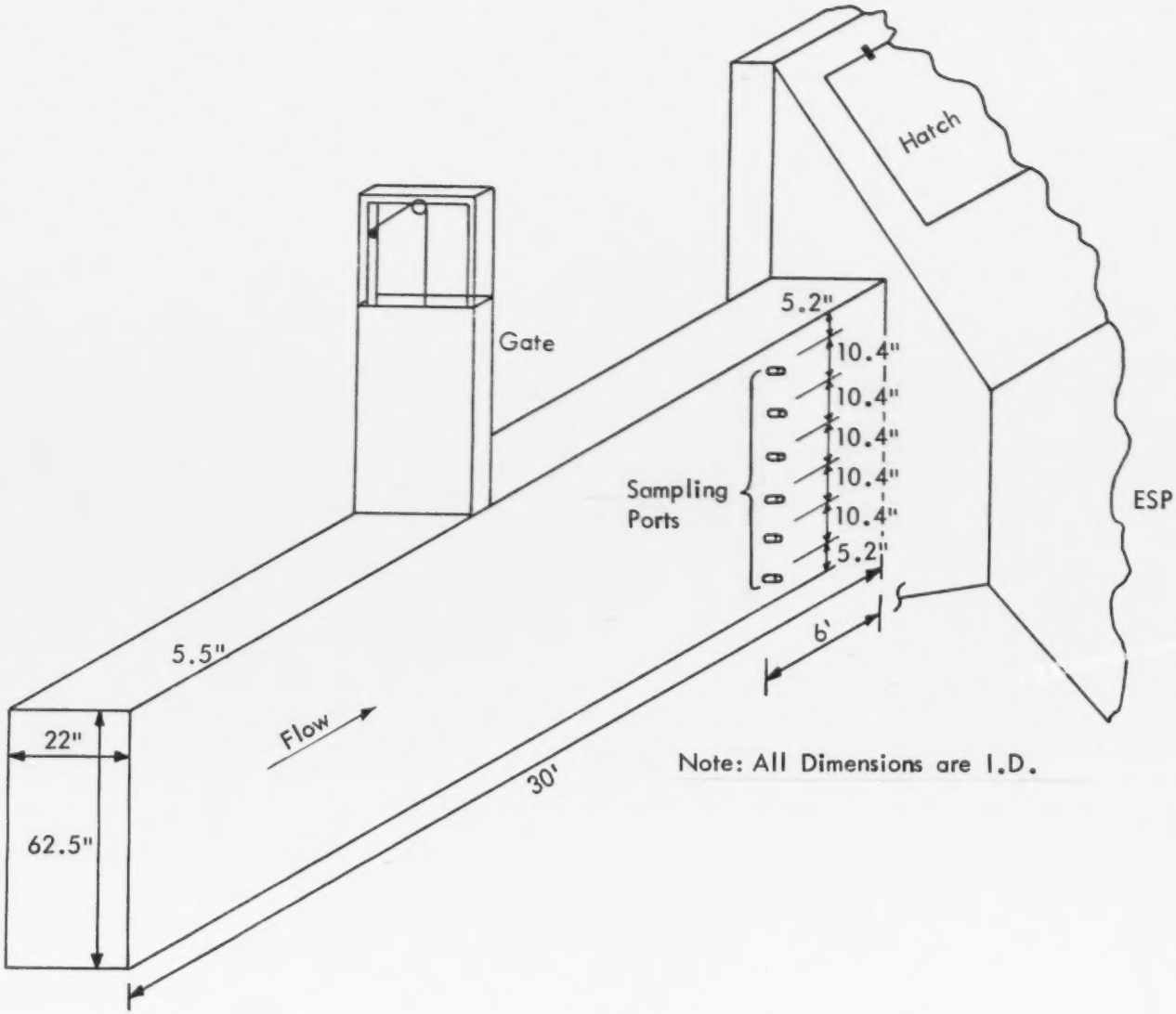


Figure B-3. Schematic illustration of the inlet bypass duct.

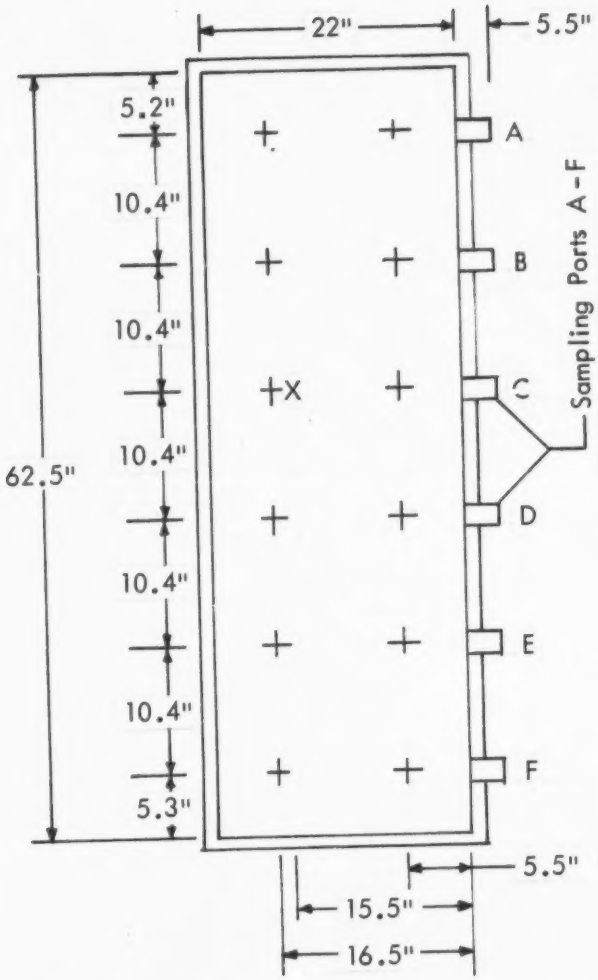


Figure B-4. Schematic illustration of the ESP inlet sampling points (the bypass duct, Figure B-4).

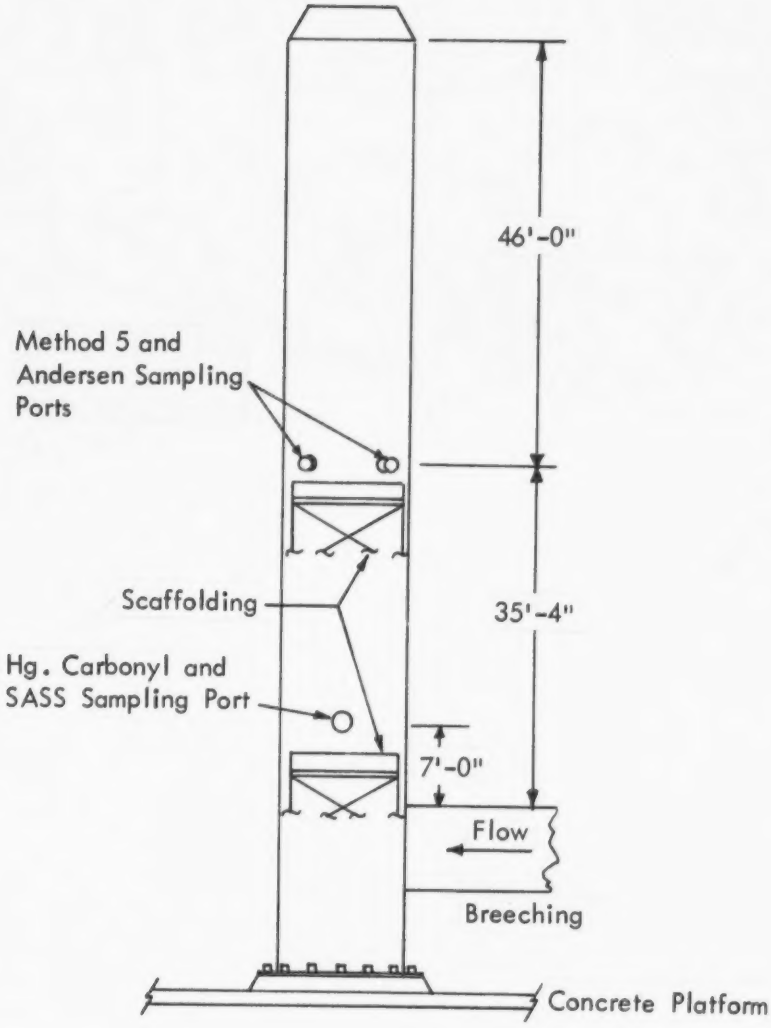


Figure B-5. Schematic illustration of Section C-C, Figure B-1 showing the stack only.

Carbonyl, Mercury, and SASS Trains Sampling Location--

The location of the sampling port for these trains was on the outlet stack 7 ft above the breeching (see Figures B-1 and B-3). Figure B-6 is a dimensioned schematic illustration of the sampling point locations for each of these trains.

Particulate Sampling Locations--

Samples obtained using the EPA Method 5 particulate sampling train and Andersen impactor particulate sizing system were drawn from two sampling ports located at a distance of 35 ft (6.7 stack diameters) downstream and 46 ft (5.2 stack diameters) upstream from any flow disturbances in the stack (see Figures B-1 and B-3). These two ports were 90 degrees apart and located in a plane perpendicular to the flow. Twenty-eight traverse points were assigned for particulate sampling (EPA Method 5) from this duct. Figure B-7 is a dimensioned schematic illustration of the location of these points and the Andersen sampling point.

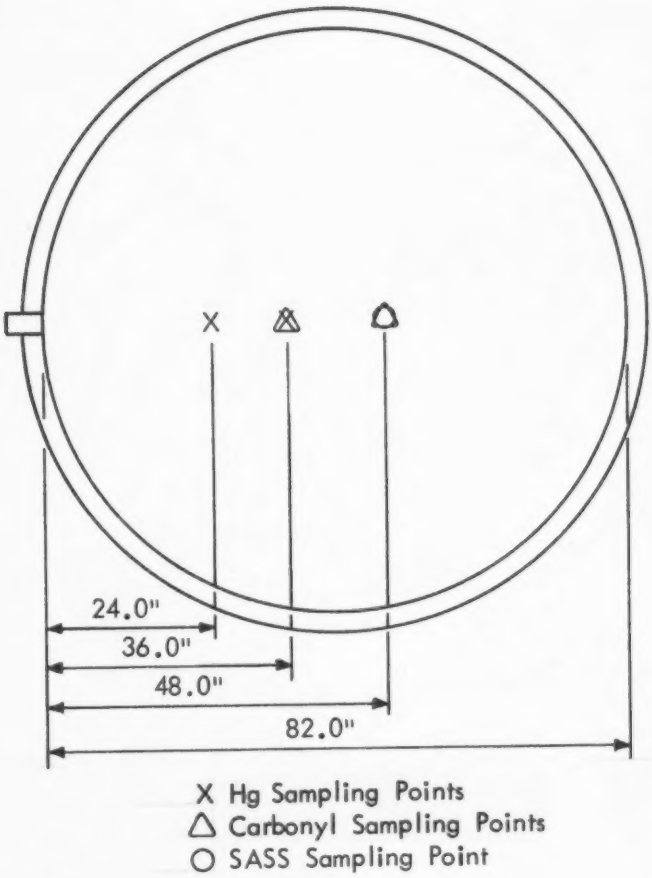


Figure B-6. Schematic illustration of the ESP outlet sampling points for aldehyde, mercury, and SASS trains.

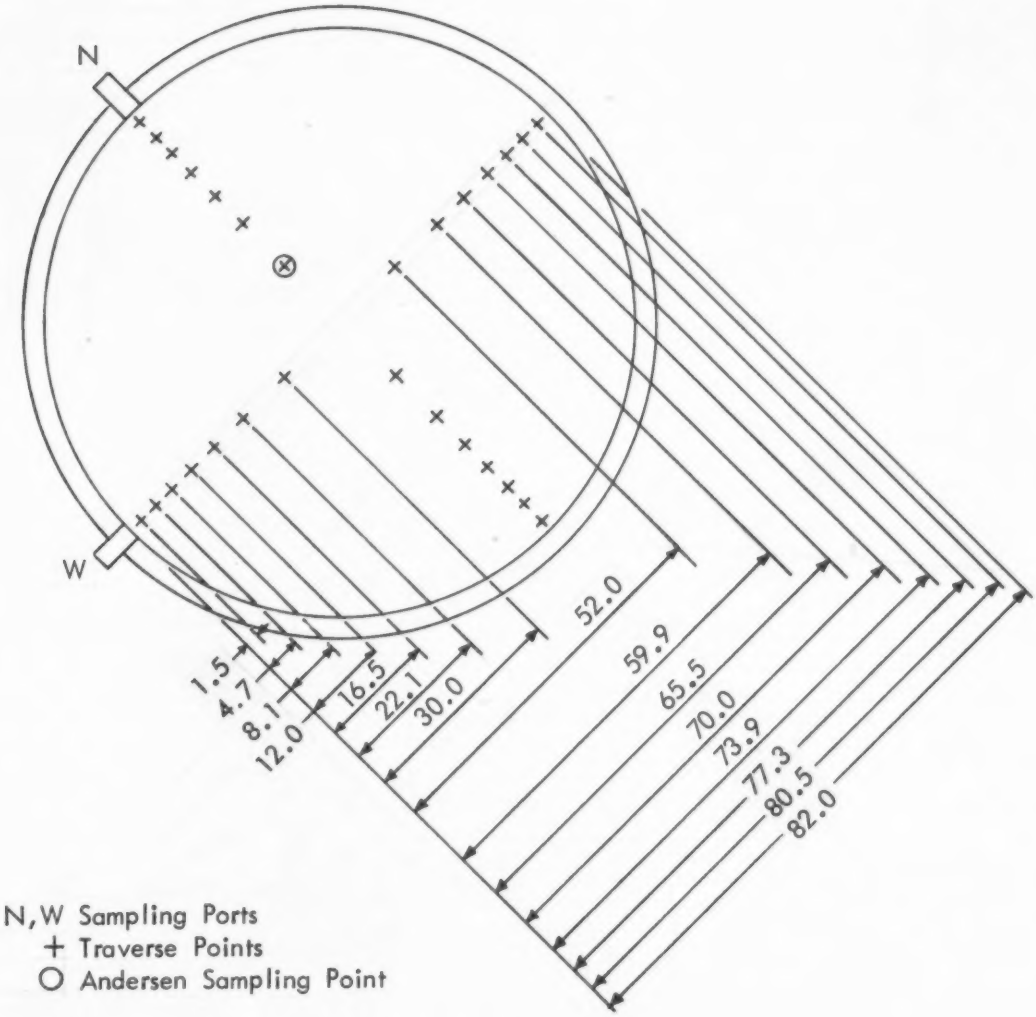


Figure B-7. Schematic illustration of the ESP outlet sampling points for Method 5 and Andersen trains.

SAMPLING AND GRAVIMETRIC ANALYTICAL PROCEDURES

Several sampling and analytical procedures were followed to conduct this project. All of these procedures are either approved, referenced or recommended by EPA. Published EPA reference methods were followed whenever they were applicable.

Particulate and Particulate Sizing

EPA Methods 1 through 5 of the Federal Register (42(160), August 18, 1977, and 36(159), August 17, 1977), were followed in the sampling and analysis of particulate matter. Figure B-8 is a schematic illustration of the sampling train used.

Initial velocities, temperatures and moisture contents of the flue gas were estimated from a previous compliance test report. The data from the initial estimate were used to preset the sampling equipment for isokinetic sampling.

Particulate sampling and analysis were accomplished according to EPA Method 5 of the above Federal Register. Twelve traverse points were utilized to sample for particulate from the ESP inlet duct. The sampling time at this inlet was 10 min per traverse point for a total of 120 min for each run. The ESP outlet was divided into 28 traverse points for particulate sampling. The sampling time at this outlet was 6 min per traverse point for a total of 168 min for each run.

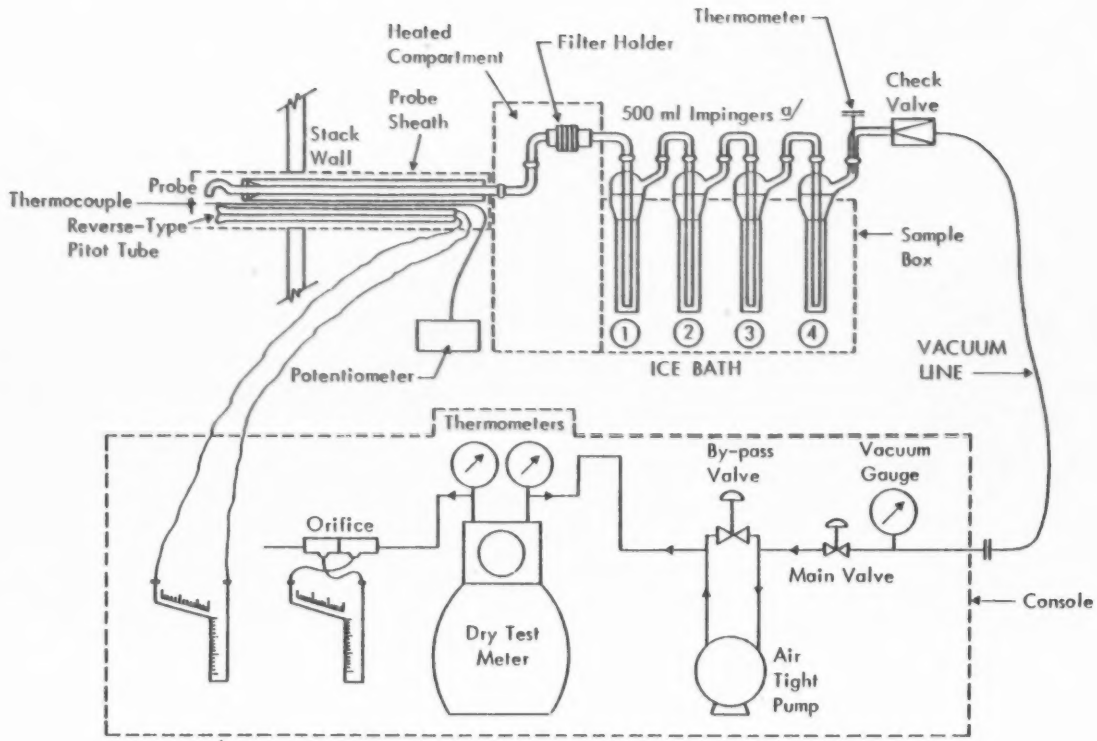
Brink Cascade Impactor (BMS II), manufactured by Monsanto EnviroChem Systems, Inc., and modified by MRI by the addition of a 7 μ cyclone at its inlet, was used as an impaction device for the particulate sizing runs. Figure B-9 is a schematic drawing of the Brink impactor in sampling position.

Andersen Cascade Impactor (Mark III), manufactured by Andersen 2000, Inc., was used to classify the particulate by size at the ESP outlet (stack). Figure B-10 is a schematic illustration of the Andersen impactor in sampling position.

MRI-established sampling and gravimetric procedures and the manufacturers' manuals for the Brink and Andersen impactors were followed in conducting the particle-sizing runs. In general, these procedures are as follows:

1. The impaction substrates were desiccated for 24 hr, weighed and placed in the impactor.

2. The temperature, velocity, moisture, static pressure and compositions of the flue gas at the sampling point were determined.



a/ Impingers 1, 3 and 4 are of the Modified Greenburg-Smith Type
Impinger 2 is of the Greenburg-Smith Design
Impinger 1 and 2 Contain 100 ml Water
Impinger 3 Empty
Impinger 4 Contains 200-300 Grams Silica Gel

Figure B-8. Schematic illustration of EPA Method 5 train used to sample for particulate matter.

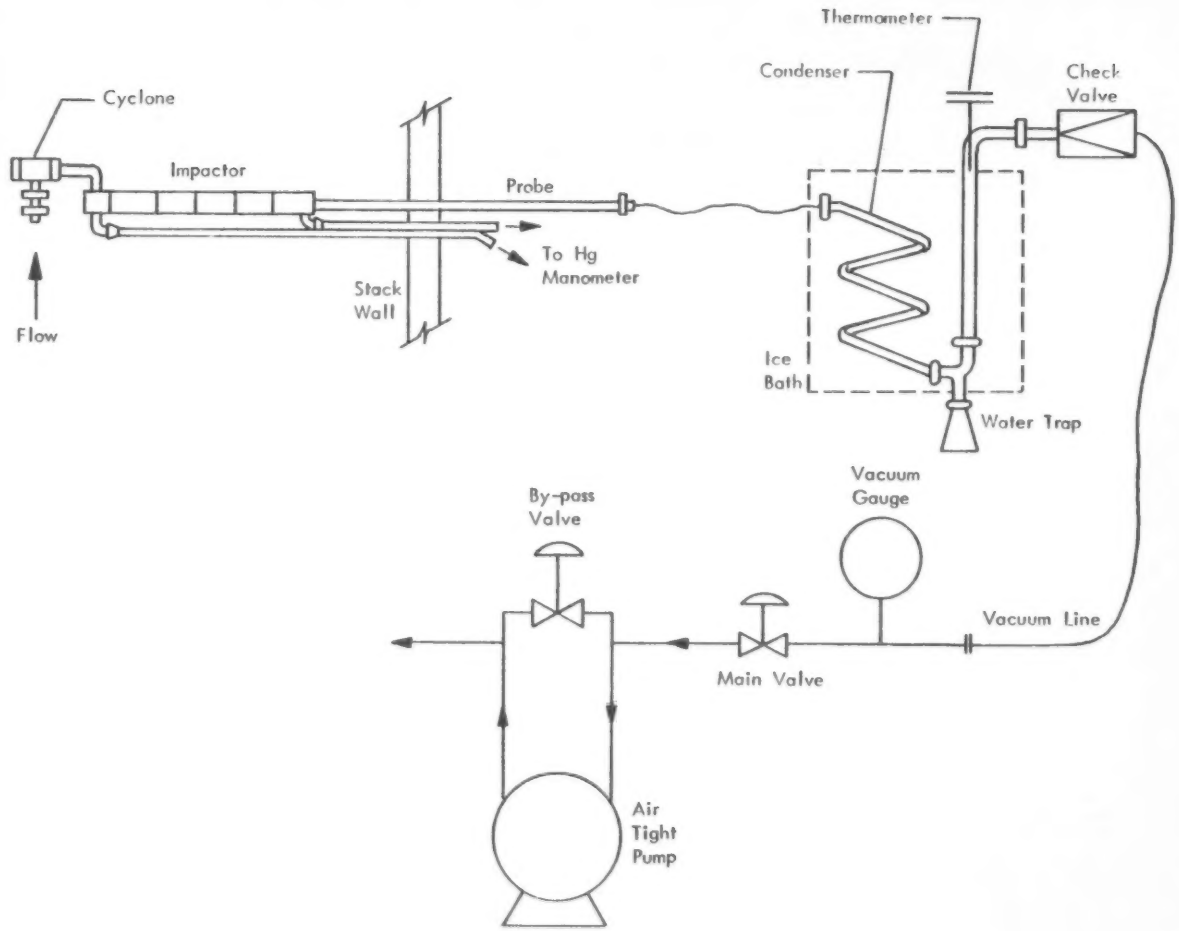


Figure B-9. Schematic illustration of the Brink impactor in sampling position.

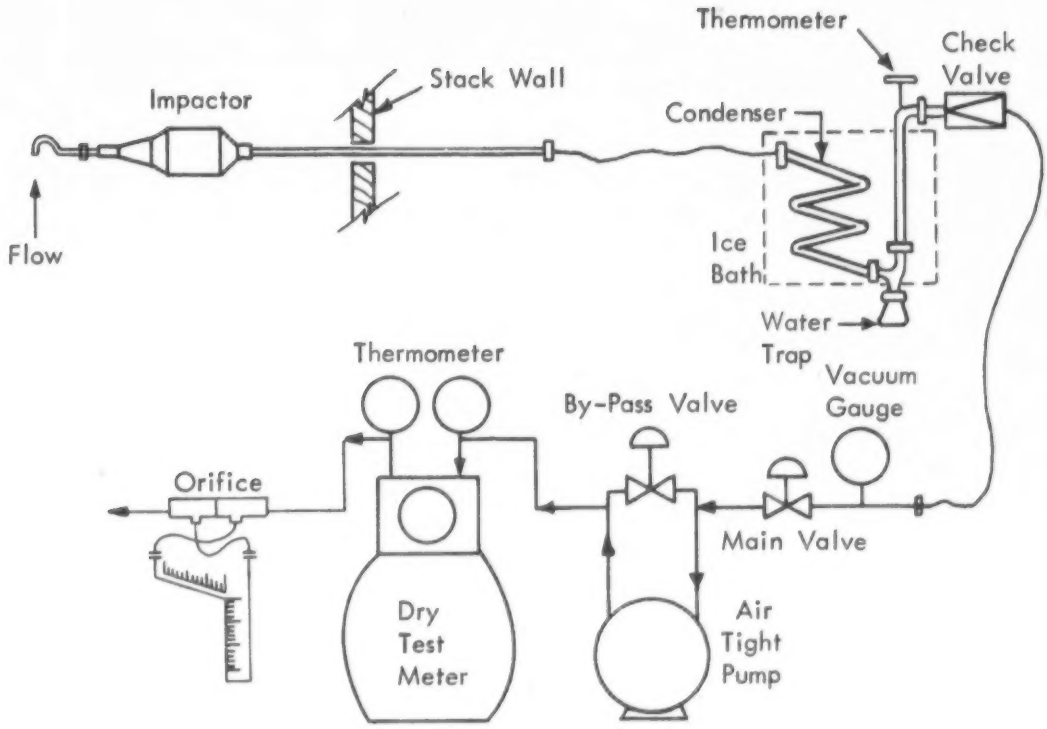


Figure B-10. Schematic drawing of the Andersen impactor in sampling position.

3. The impactor's tip diameter was chosen conveniently using Method 5 type nomograph.

4. The sample flow rate through the impactor was calculated to the dry test meter conditions such that, the face input velocity of the impactor's tip is equal to the flue gas velocity at the sampling point (isokinetic sampling).

5. The impactor was then preheated in the stack for 30 min at the predetermined sampling point with the impactor's tip capped with stainless steel cap.

6. The flow rate was set at the meter (Step 4) for isokinetic sampling.

7. The sampling was then started at the set flow rate (Step 6) and after opening the impactor's tip (Step 5).

Continuous Monitoring for Gases

The continuous monitoring system for gases consisted of the following gas analyzers:

a. IBC O_2 analyzer; operates on the principle of polarographic cell.

b. Bendix NO_x analyzer; operates on the principle of chemiluminescent.

c. Beckman SO_2 analyzer; operates on the principle of NDIR.

d. Beckman HC analyzer; operates on the principle of FID.

e. Beckman CO analyzer; operates on the principle of NDIR.

The continuous monitoring system drew its sample from a common manifold. The sampling interface between the sampling point (see Figure B-1) and the manifold, which is about 30 ft in length, consisted of a 1/4 in. stainless steel tubing, coaxially jacketed with 1/2 in. copper tubing. Plant low pressure steam was piped into the copper jacket at the sampling port, and then flowed freely inside the copper tubing down to the trailer which housed the manifold and the analyzers. The purpose of this steam jacket was to keep the flue gas in the stainless steel sampling line above the dew point temperature.

Analyzer manuals were followed in operating this continuous sampling system.

Carbonyl Train

Figure B-11 is a schematic drawing of this train, showing the contents of the impinger collectors. Samples were drawn from the stack outlet (Figures B-1, B-3, and B-6). The train was operated for 60 min at a constant flow rate of 0.5 cfm.

Mercury Train

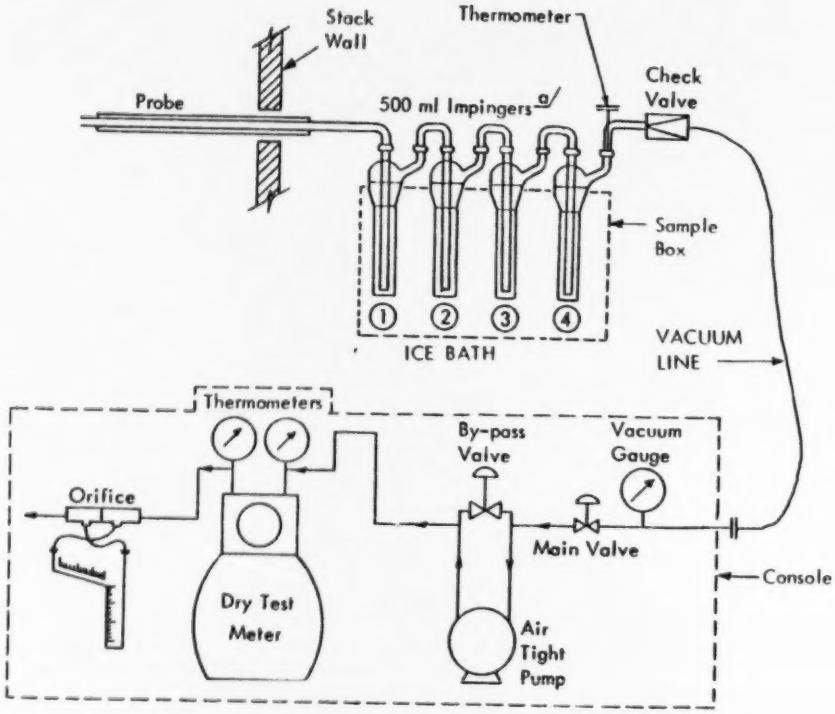
Mercury samples were drawn from the same location used for the carbonyl train. Figure B-12 is a schematic illustration of this train in sampling position. The procedures presented at the 1973 ACS Annual Meeting (Chicago, Illinois, August 26 through 31, 1973) under the heading, "Sampling and Analysis of Mercury Vapor in Industrial Streams Containing Sulfur Dioxide," were followed in sampling and analyzing for mercury.

SASS Train

The operating manual for the SASS train as published by EPA, "Level 1 - Environmental Assessment," (EPA-600/2-76-160a, June 1976), was followed for these tests. This system is shown schematically in Figure C-1 in sampling position.

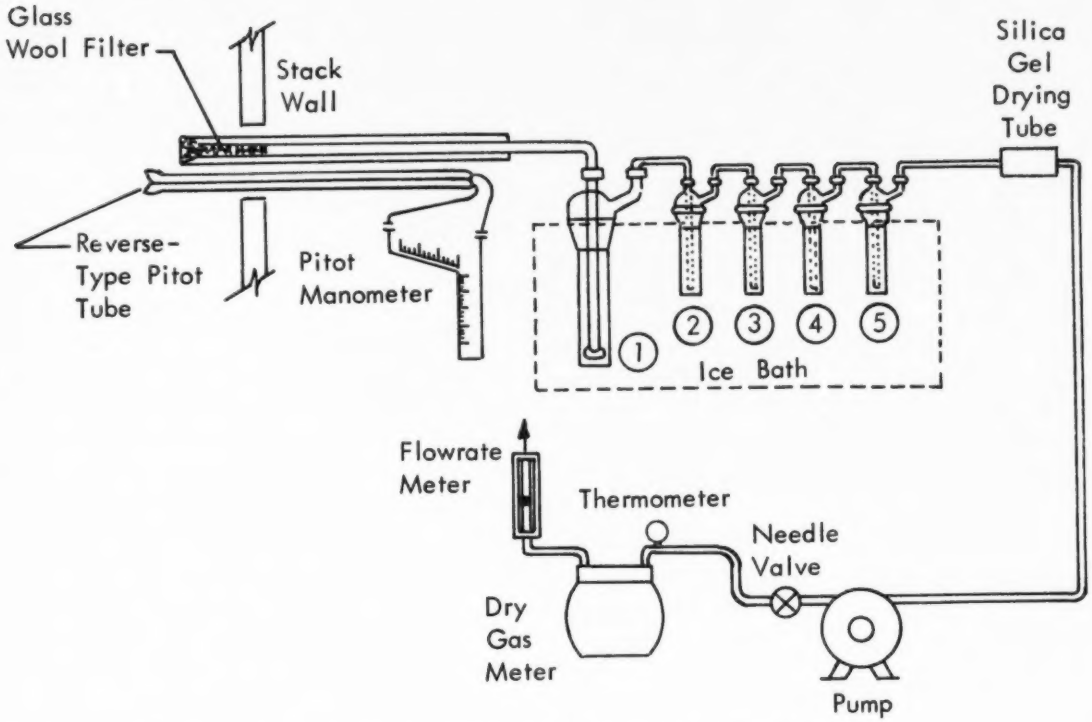
Opacity

Opacity readings were taken from the plant's transmissometer installed in the outlet duct of the ESP just upstream of the ID fan. The sky was overcast during the test period, which prevented our observer from reading the opacity according to EPA Method 9.



a/ Impingers 1 and 2 are of Greenburg-Smith Type
each contains 100ml of 1% Sodium Bisulfate Solution
Impinger 3 is empty
Impinger 4 contains 200 grams Silica Gel

Figure B-11. Schematic diagram of the aldehyde train.



① Greenburg-Smith Impinger (200 ml of 2% Na_2CO_3)
②, ③, ④ Midget Bubbler (20 ml KM_nO_4)
⑤ Midget Impinger (Dry)

Figure B-12. Schematic illustration of the mercury sampling train in sampling position.

APPENDIX C

DESCRIPTION OF SASS EQUIPMENT AND ANALYSIS

The SASS is a method prescribed by EPA for environmental assessment work. It is somewhat similar to, but more complex than, the EPA Method 5 train. Basic components of the SASS train are shown in Figure C-1. It is different from the Method 5 train in that the filter is preceded by three cyclones and the filter is followed by an XAD-2 cartridge for collection of organics. Also, the impingers contain special solutions for collection of vaporous metals (e.g., Hg).

Analysis of the SASS train components, as prescribed by EPA's Level 1 environmental assessment procedure, is quite complex. A tabular presentation of the required analysis is shown in Table C-1. This matrix is in accordance with a Level 1 assessment, with the exception of morphology and bioassay. However, for the purposes of this test program, MRI has added certain other analyses as indicated in Table C-1.

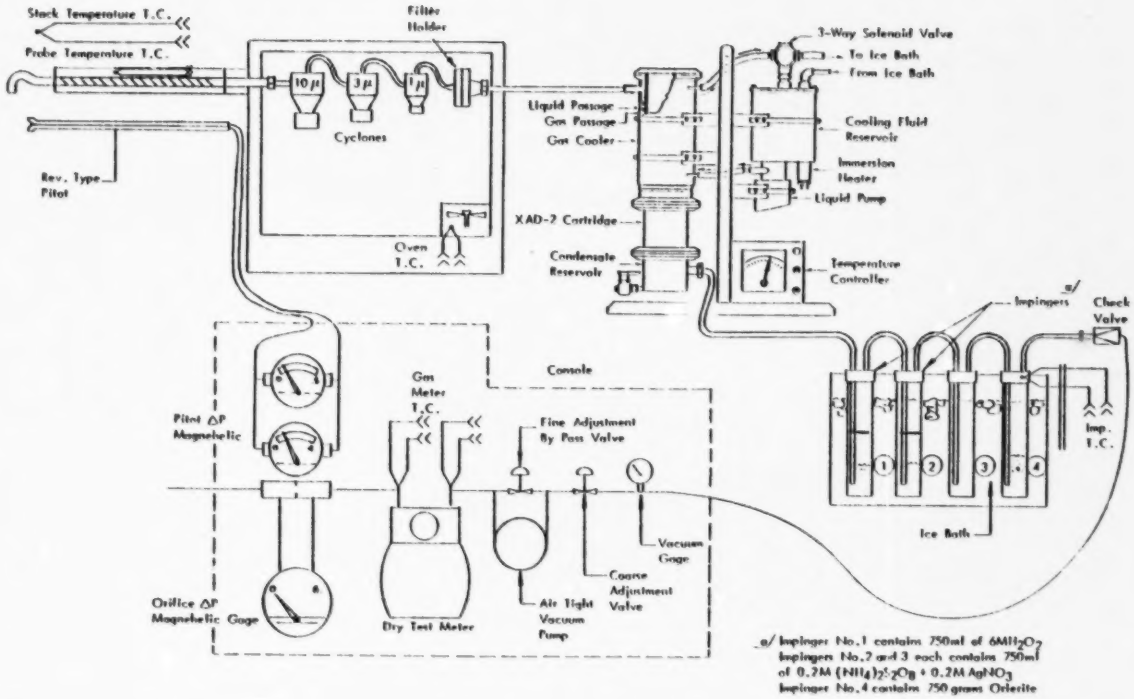


Figure C-1. Schematic of source assessment sampling system.

TABLE C-1. ANALYSIS MATRIX FOR SASS TRAIN COMPONENTS

	Particulate							
	Probe and cyclone rinse	10 μm	3 μm	1 μm	Filter	XAD-2 resin	Aqueous condensate	Impinger solutions
EPA LEVEL 1 PROTOCOL								
SSMS	X	X	X	X	X	X	X	X[a]
As, Sb, and Hg by atomic absorption		X	X	X	X	X	X	X
CH_2Cl_2 extraction		Combined		Combined				
Gravimetric		X		X		X	X	
IR analysis		X		X		X	X	
LRMS analysis		X		X		X	X	
LC (7 fractions)[b]		X		X		X	X	
ADDITIONAL ANALYSES SELECTED BY MRI								
PCB material		X		X		X	X	
PAH compounds		X		X		X	X	
Corrosion test							X	X

a/ Hydrogen peroxide impinger only.

b/ Dry and weigh each fraction. Analyze by IR and LRMS.

APPENDIX D

DATA TABLES FOR SAM-1A

TABLE D-1. SAM/1A SUMMARY SHEET

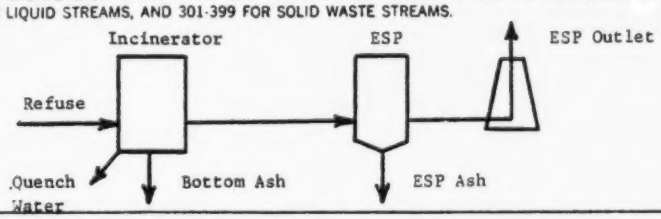
Form IA01

1. SOURCE AND APPLICABLE CONTROL OPTIONS

Braintree Refuse Fired Incinerator

2. PROCESS THROUGHPUT OR CAPACITY 4.5 Mg/hr (5 tons/hr)

3. USE THIS SPACE TO SKETCH A BLOCK DIAGRAM OF THE SOURCE AND CONTROL ITEMS SHOWING ALL EFFLUENT STREAMS. INDICATE EACH STREAM WITH A CIRCLED NUMBER USING 101-199 FOR GASEOUS STREAMS, 201-299 FOR LIQUID STREAMS, AND 301-399 FOR SOLID WASTE STREAMS.



4. LIST AND DESCRIBE GASEOUS EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

101 ESP Outlet Gases
102
103
104
105
106
107

5. LIST AND DESCRIBE LIQUID EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

201 Bottom Ash Quench Water
202
203
204
205
206

6. LIST AND DESCRIBE SOLID WASTE EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

301 Incinerator Bottom Ash
302 ESP Ash
303
304
305
306

7. IF YOU ARE PERFORMING A LEVEL 1 ASSESSMENT, COMPLETE THE IA02-LEVEL 1 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE. IF YOU ARE PERFORMING A LEVEL 2 ASSESSMENT, COMPLETE THE IA02-LEVEL 2 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE.

TABLE D-1. (continued)

8. LIST SUMS FROM LINE 7, FORMS IA02, IN TABLE BELOW

DEGREE OF HAZARD AND TOXIC UNIT DISCHARGE RATES BY EFFLUENT STREAM

GASEOUS					LIQUID					SOLID WASTE				
STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES	
	HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED
	–	–	(m^3/sec)			–	–	(l/sec)			–	–	(g/sec)	
101	1.3E4	1.1E2	1.2E5	1.1E3	201	< 20	< 0.2	<5.6	<0.76					
										301	3.8E3	1.7E6	1.7E6	7.8E8
										302	1.3E3	2.0E5	6.9E3	1.1E6
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

9. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM DEGREES OF HAZARD FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

TOTAL DEGREE OF HAZARD

	HEALTH-BASED		ECOLOGICAL-BASED	
GASEOUS	(Σ COL. B) 9A	1.3E4	(Σ COL. C) 9A'	1.1E2
LIQUID	(Σ COL. G) 9B	< 2.0E1	(Σ COL. H) 9B'	<2.0E-1
SOLID WASTE	(Σ COL. L) 9C	5.1E3	(Σ COL. M) 9C'	1.9E6

10. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM TOXIC UNIT DISCHARGE RATES FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

TOTAL TOXIC UNIT DISCHARGE RATES

	HEALTH-BASED		ECOLOGICAL-BASED	
GASEOUS (m^3/sec)	(Σ COL. D) 10A	1.2E5	(Σ COL. E) 10A'	1.1E3
LIQUID (l/sec)	(Σ COL. I) 10B	<7.6E1	(Σ COL. J) 10B'	<7.6E1
SOLID WASTE (g/sec)	(Σ COL. N) 10C	1.7E6	(Σ COL. O) 10C'	7.8E8

11. NUMBER OF EFFLUENT STREAMS

GASEOUS	11A	1
LIQUID	11B	1
SOLID WASTE	11C	2

12. LIST POLLUTANT SPECIES KNOWN OR SUSPECTED TO BE EMITTED FOR WHICH A MATE IS NOT AVAILABLE

See Tables

TABLE D-2. BOTTOM ASH WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1

Form IA02 Level 1

Page 1 / 4

1. SOURCE/CONTROL OPTION

Braintree Refuse Fired Incinerator

2. EFFLUENT STREAM

301 (CODE #) Bottom Ash (NAME)

3. EFFLUENT STREAM FLOW RATE

Q = 447.4 g/s

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g Ash	µg/g	µg/g	–	–	–	–	–	–	g/s	g/s
Uranium	≤ 0.43										
Thorium	0.81										
Bismuth	8.3	12	N	0.69						309	
Lead	440	0.50	0.10	880		4,400		X	X	393,712	1,968,560
Thallium	<0.15	3	N	0.50						224	
Mercury	-	0.02	0.50								
Gold	< 0.1	N	N								
Platinum	< 0.1	0.06	N	1.67						747.16	
Iridium	< 0.1										
Osmium	< 0.1										
Rhenium	-										
Tungsten	≤ 1.1	30	N	0.04						17.90	
Tantalum	≤ 0.52										
Hafnium	≤ 1.4	Hf^{+4} 1.5	N	0.93						416.08	

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a 3,827

ECOLOGICAL MATE BASED (Σ COL. G) 5b 1,739,390

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 49

ECOLOGICAL 6b 23

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a 1,712,385

ECOLOGICAL MATE BASED (Σ COL. L) 7b 778,203,524

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE D-2. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 301

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN-TRATION	HEALTH MATE CONCEN-TRATION	ECOLOGICAL MATE CONCEN-TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g Ash	µg/g	µg/g	—	—	—	—	—	—	g/s	g/s
Lutecium	≤ 0.26										
Ytterbium	≤ 0.26										
Thulium	≤ 0.13										
Erbium	< 0.33										
Holmium	≤ 0.16										
Dysprosium	≤ 0.53	460	N	0.0015						0.67	
Terbium	≤ 0.26										
Gadounium	≤ 1.9										
Europium	≤ 0.78										
Samarium	≤ 0.79	1,600	N	0.00049						0.22	
Neodymium	6.7	N	N								
Praseodymium	4.5	1,400	N	0.003						1.34	
Cerium	19	1,100	N	0.02						8.95	
Lanthanum	12	3,400	N	0.0035						1.57	
Barium	≥ 3,400	10	5	340		680		X	X	152,116	304,232
Cesium	≤ 0.38	CE^+ 2,500	N	0.00015						0.07	
Iodine	≤ 0.87	I^- N	N								
Tellurium	< 0.1	3	N	0.03						13.42	
Antimony	30	15	0.40	2		75		X	X	894.8	33,555
Tin	96	N	N								
Indium	-	3	N								
Cadmium	2.2	0.10	0.002	22		1,100		X	X	9,842.8	429,140
Silver	4.6	0.50	0.1	9.2		46		X	X	4,116	20,580
Palladium	< 0.1										
Rhodium	< 0.1	0.03	N	3.3				X		1,476.4	

TABLE D-2. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 301

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN-TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	µg/g Ash	µg/g	µg/g	—	—	—	—	—	—	g/s	g/s
Rothenium	< 0.1	N	N								
Molybdenum	8.2	150	14	0.05		0.59				22.37	263.97
Niobium	4.3	650	N	0.01						4.47	
Zirconium	62	15	N	4.13				X		1,847.76	
Yttrium	3.5	30	N	0.12						53.69	
Strontium	250	92	N	2.72				X		1,216.9	
Robidium	17	3,600	N	0.0047						2.10	
Bromine	10	N	N								
Selenium	0.41	0.1	0.5	4.10		0.82		X		1,834.3	366.87
Arsenic	12	0.50	0.10	24		120				10,737.6	53,688
Germanium	≤ 0.48	17	N	0.03						13.42	
Gallium	3.4	150	N	0.02						8.95	
Zinc	~1,000	50	0.20	20		5,000		X	X	8,948	2,237,000
Copper	~ 900	10	0.10	90		9,000		X	X	40,266	4,026,600
Nickel	40	0.45	0.02	88.89		2,000		X	X	39,769.4	894,800
Cobalt	6.7	1.5	0.5	4.47		13.40		X	X	1,999.9	5,995.2
Iron	≥ 3,900	3.0	0.5	1,300		7,800		X	X	581,620	3,489,720
Manganese	250	0.50	0.20	500		1,250		X	X	223,700	559,250
Chromium	150	0.50	0.50	300		300		X	X	134,220	134,220
Vanadium	90	5	0.30	18		300		X	X	6,711	134,220
Titanium	≥ 4,000	1,800	1.6	2.22		2,500		X	X	993.2	1,118,500
Scandium	0.64	1,600	N	0.0004						0.18	
Calcium	≥ 8,500	480	32	17.71		265.63		X	X	7,923.5	118,842
Potassium	~ 1,600	N	N								
Chlorine	120	2,600	N	0.05						22.37	

TABLE D-2. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM 1A02, LEVEL 1

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 301

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN-TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	µg/g Ash	µg/g	µg/g	—	—	—	—	—	—	g/s	g/s
Sulfur	2,300	N	N								
Phosphorus	1,700	30	0.001	56.67		1,700,000		X	X	25,354.2	760,580,000
Silicon	> 0.9%	300	N	30.00				X		13,422	
Aluminum	> 0.9%	160	2	56.25		4,500		X	X	25,166	2,013,300
Magnesium	≥ 2,400	180	170	13.33		14.12		X	X	5,963.8	6,317.3
Sodium	≥ 3,700	1,600	N	2.31				X		1,033.5	
Fluorine	57	75	N	0.76						340	
Oxygen	-										
Nitrogen	-	N	N								
Carbon	-	160	N								
Boron	71	93	50	0.76		1.42			X	340	635.3
Berylium	≤ 0.25	0.06	N	4.71				X		2,107.3	
Lithium	18	0.70	0.75	25.71		24.00		X	X	11,502.7	10,737.6

TABLE D-3. BOTTOM ASH WORKSHEET NOTES

NOTES

Stream 301

N: not yet assigned
blank - no entry given

Run 1	Run 2	Run 3
$\frac{43{,}540\ \text{lb}}{9.58\ \text{hr}} = 4{,}543\ \text{lb/hr}$	$\frac{27{,}400\ \text{lb}}{9\ \text{hr}} = 3{,}044\ \text{lb/hr}$	$\frac{24{,}340\ \text{lb}}{8\ \text{hr}} = 3{,}042\ \text{lb/hr}$

avg. = 3,543 lb/hr $\frac{\text{kg}}{2.2\ \text{lb}}\ \frac{1{,}000\ \text{g}}{\text{kg}}\ \frac{\text{hr}}{3{,}600\text{S}} = 447.4\ \text{g/s}$

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

Stream 301

When $\geq$, $\leq$, $>$, or $\sim$ used, found degree of hazard associated with value given.

If only ionic form of element given, that value was used and noted as such.

$Hf \equiv Hf^{4+}$
$Rh \equiv Rh^{3+}$
$Nb \equiv Nb^{+3,+5}$
$Zr \equiv Zr^{+4}$
$Y \equiv Y^{3+}$
$Fe \equiv Fe^{+2,+3}$
$Ca \equiv Ca^{+2}$

$Cl \equiv Cl^{-}$
$F \equiv F^{-}$

same assumptions used on ESP Ash

TABLE D-4. QUENCH WATER WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1

Form IA02 Level 1

Page 1 / 1

1. SOURCE/CONTROL OPTION

Braintree

2. EFFLUENT STREAM

201 (CODE #) Bottom Ash Quench Water (NAME)

3. EFFLUENT STREAM FLOW RATE

Q = 3.78 liter/sec

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/ℓ	µg/ℓ	µg/ℓ	—	—	—	—	—	—	ℓ/s	ℓ/s
Phenol	<100	5.0	5.0E2	<20		<0.20		X		<75.6	<0.76

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a 20

ECOLOGICAL MATE BASED (Σ COL. G) 5b 0.2

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a

ECOLOGICAL 6b

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a 75.6

ECOLOGICAL MATE BASED (Σ COL. L) 7b 0.76

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE D-5. ESP ASH WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1

Form IA02 Level 1

1. SOURCE/CONTROL OPTION

Braintree

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2. EFFLUENT STREAM

302 (CODE #) ESP Ash (NAME)

3. EFFLUENT STREAM FLOW RATE

Q = 5.341 g/s

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/s	g/s
U	0.81										
Th	≥ 1.9										
Bi	58	12	N	4.83				X		25.80	
Pb	≥ 500	0.50	0.10	1,000		5,000		X	X	5,341	26,705
Tl	≥ 0.24	3	N	0.08						0.43	
Hg	NR	0.02	0.50								
Au	<0.1	N	N	N							
Pt	<0.1	0.06	N	1.67				X		8.92	
Ir	<0.1										
Os	<0.1										
Re	NR										
W	6.3	30	N	0.21						1.12	
Ta	0.84	-	-								
Hf	2.1	1.5	N	1.40				X		7.48	

IF MORE SPACE IS NEEDED USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL E) 5a 1,283

ECOLOGICAL MATE BASED (Σ COL G) 5b 1.979×10^5

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 52

ECOLOGICAL 6b 24

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL K) 7a 6,852

ECOLOGICAL MATE BASED (Σ COL L) 7b 1.057×10^6

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE D-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02. LEVEL 1

Page 2 A

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 302

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/s	g/s
Lu	≤1.5										
Yb	1.2										
Tm	0.26										
Er	0.73										
Ho	0.37										
Dy	1.6	460	N	3.48×10^{-3}						0.02	
Tb	0.41										
Gd	1.5										
Eu	0.63										
Sm	3.4	1,600	N	2.1E-3						0.01	
Nd	9.2	N	N								
Pr	4.0	1,500	N	2.67E-3						0.01	
Ce	65	1,100	N	0.06						0.32	
La	16	3,400	N	4.7×10^{-3}						0.03	
Ba	900	10	5	90		180		X	X	480.69	961.4
Cs	0.91	2,500	N	3.64E-4						0.02	
I	5.5	N	N								
Te	≤0.21	3	N	0.07						0.37	
Sb	270	15	0.40	18		675		X	X	96.14	3,605.2
Sn	1,200	N	N								
In	NR	3	N								
Cd	37	0.10	0.002	370		18,500		X	X	1,976.2	98,808.5
Ag	21	0.50	0.1	42		210		X	X	224.3	1,121.6
Pd	<0.1										
Rh	<0.1	0.03	N	3.33				X		17.8	

TABLE D-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

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SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 302

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (G x LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/s	g/s
Ru	<0.1	N	N								
Mo	68	150	N	0.45		4.86			X	2.4	25.96
Nb	24	650	N	0.04						0.21	
Zr	91	15	N	6.1				X		32.6	
Y	6.2	30	N	0.21						1.12	
Sr	290	92	N	3.15				X		16.8	
Rb	34	3,600	N	0.01						0.05	
Br	280	N	N								
Se	6.0	0.1	0.5	60		12		X	X	320.5	64.1
As	15	0.50	0.10	30		150		X	X	160.2	801.2
Ge	2.4	17	N	0.14						0.75	
Ga	5.7	150	N	0.04						0.21	
Zn	≥ 500	50	0.20	10		2,500		X	X	53.41	13,352.5
Cu	720	10	0.10	72		7,200		X	X	384.0	38,455.2
Ni	200	0.45	0.02	444.4		10,000		X	X	2,373.5	53,410
Co	68	1.5	0.5	45.33		136		X	X	242.1	726.4
Fe	> 750	3.0	0.5	250		1,500		X	X	1,335.3	8,011.5
Mn	~1,600	0.50	0.20	3,200		8,000		X	X	17,091	42,728
Cr	560	0.50	0.50	1,120		1,120		X	X	5,981.9	5,981.9
V	100	5	0.30	20		333.3		X	X	106.8	1,780.2
Ti	≥ 500	1,800	1.6	0.28		312.5			X	1.50	1,669.1
Sc	33.2	1,600	N	2.0E-3						0.01	
Ca	>1,000	480	32	2.08		31.25		X	X	11.1	166.9
K	>1,000	N	N								
Cl	> 900	2,600	N	0.35						1.87	

TABLE D-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM 1A02, LEVEL 1

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 302

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/g	μg/g	μg/g	—	—	—	—	—	—	g/s	g/s
S	≥750	N	N								
P	>1,000	30	0.001	33.33		$1x10^6$		X	X	178.0	$5.34x10^6$
Si	>1,000	300	N	3.33				X		17.8	
Al	>1,000	160	2	6.25		500		X	X	33.4	2,670.5
Mg	>900	180	170	5		5.29		X	X	26.7	28.3
Na	>1,000	1,600	N	0.63						3.36	
F	1,700	75	N	22.67				X		121.1	
O	NR										
N	NR	N	N								
C	NR	160	N								
B	285	93	50	3.06		5.70		X	X	16.34	30.4
Be	≤0.50	0.06	N	8.33				X		44.49	
Li	150	0.70	0.75	214.3		200		X	X	1,144.6	1,068.2
Br^-	516.8	N	N								
Cl^-	41,330	2,600	N	15.90				X		84.9	
CN^-	<0.7	1.0	0.5	0.7		1.40			X	3.74	7.48
F^-	580	75	N	7.73				X		41.3	
NO_3^-	<5	N	N								
SO_4^{--}	10,400	N	N								

TABLE D-6. ESP ASH WORKSHEET NOTES

NOTES

Ash Rate - Inlet/Outlet

$$= (25.969 - 6.741)\frac{kg}{hr} = 19.228\ \frac{kg}{hr}\ \frac{hr}{3{,}600\ s}\ \frac{1{,}000\ g}{kg} = 5.341\ \frac{g}{s}$$

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

TABLE D-7. ESP OUTLET WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1 — **Form IA02 Level 1**

1. SOURCE/CONTROL OPTION: Braintree

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2. EFFLUENT STREAM: 101 (CODE #) ESP Outlet Gas (NAME)

3. EFFLUENT STREAM FLOW RATE: Q = 591.4 dscm/min = 9.86 m^3/s (gas = m^3/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	–	–	–	–	–	–	m^3/s	m^3/s
FLUE GAS ANALYSIS											
CO_2	8.3E7	-	-								
O_2	2.3E8	-	-								
CO	5.9E5	4.0E4	1.2E5	14.8		4.9		X	X	146	48
HC	(11.3 ppm)	-	-								
NO_x	1.06E5	0.0E2	N	118				X		1,164	
SO_2	1.4E5	1.3E4	N	10.8				X		107	
C=O	(1.34 ppm)	-	-								
Hg	~560	50	10	11.2		56		X	X	110	552
Cl^-	~120	7.0E3	N	0.02						0.20	
F^-	<3.5	2.5E3	N	<1.4E3						<0.01	
Br^-	<8	N	N								
$C\equiv N^-$	<2	1.1E4	3.4E4	<1.8E4						<1.8E-3	

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD
HEALTH MATE BASED (Σ COL. E) 5a 13,905
ECOLOGICAL MATE BASED (Σ COL. G) 5b 111
(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES
HEALTH 6a 173
ECOLOGICAL 6b 8

7. TOXIC UNIT DISCHARGE SUM
HEALTH MATE BASED (Σ COL. K) 7a 137,026
ECOLOGICAL MATE BASED (Σ COL. L) 7b 1,090
(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$		—	—	—	—	—	—	m^3/s	m^3/s
I. Front Half (Particulate) of SASS Train											
Sb	75.4	5.0E2	N	0.15						0.02	
As	11.9	2.0	N	6.0				X		0.61	
Hg	4.2	50	10	0.08		0.42				0.01	0.04
SSMS											
U	0.026	-	-								
Th	≤0.121	-	-								
Bi	~32	410	N	0.08						0.79	
Pb	~432	150	N	2.9				X		28.4	
Tl	≤0.06	100	N	≤6E-4						≤0.01	
Hg	NR	50	10								
Au	<0.012	N	N								
Pt	<0.005	2.0	N	<2.5E-3						<0.02	
Ir	<0.005	-	-								
Os	<0.005										
Rl	NR	-	-								
W	0.402	1,000	N	4.0E-4						3.9E-3	
Ta	0.042	5,000	N	8.4E-6						8.3E-5	
Hf	≤0.070	500	N	<1.4E-4						<1.4E-3	
Lu	<0.022	-	-								
Yb	<0.042	-	-								
Tm	<0.01	-	-								
Er	<0.027	-	-								
Ho	≤0.007	-	-								

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM 1A02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	—	—	—	—	—	—	m^3/s	m^3/s
Dy	≤0.014	9,300	N	≤1.5E-6						≤1.5E-5	
Tb	≤0.163	-	-								
Gd	<0.59	-	-								
Eu	≤0.337	-	-								
Sm	≤0.134	5.3E4	N	≤2.5E-6						≤2.5E5	
Nd	0.512	N	N								
Pr	0.412	5.1E4	N	8.1E-6						8.0E-5	
Ce	0.963	8.2E4	N	1.2E-5						1.2E-4	
La	0.819	1.1E5	N	7.4E-6						7.3E-5	
Ba	~29.7	5.0E2	N	0.06						0.59	
Cs	≤0.403	-	-								
I	≤3.7	N	N								
Tp	≤0.021	1.0E2	N	≤2.1E-4						≤2.1E-3	
Sb	~92	5.0E2	N	0.18						1.8	
Sn	~260	N	N								
In	NR	1.0E2	N								
Cd	35.4	10	N	3.5				X		34.9	
Ab	7.7	10	N	0.77						7.6	
Pd	<0.005	-	-								
Rh	<0.005	1.0	N	<5E-3						<0.05	
Ru	<0.005	-	-								
Mo	16.7	5.0E3	N	3.3E-3						0.03	
Nb	0.22	2.2E4	N	1.0E-5						9.9E-5	
Zr	0.53	5.0E3	N	1.1E-4						1.1E-3	
Y	0.81	1.0E3	N	8.1E-4						0.01	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02. LEVEL 1

SOURCE/CONTROL OPTION _____ EFFLUENT STREAM NO _____

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	—	—	—	—	—	—	m^3/s	m^3/s
Sr	13.0	3.1E3	N	4.2E-3						0.04	
Rb	8.9	1.2E5	N	7.4E-5						7.3E-4	
Br	~ 207	N	N								
Se	≤ 1.4	2.0E2	N	0.01						0.10	
As	~ 19	2.0	N	9.5				X		94	
Ge	6.9	5.6E2	N	0.01						0.10	
Ga	2.1	5.0E2	N	4.2E-4						4.1E-3	
Zn	> 488	4.0E3	N	0.12						1.2	
Cu	~ 89	2.0E2	N	0.4						3.9	
Ni	10.3	15	N	0.69						6.8	
Cs	19.4	50	N	0.39						3.9	
Fe	> 301	1.0E3	N	0.30						3.0	
Mn	~ 38	5.0E3	N	0.01						0.10	
Cr	25.8	1.0	N	25.8				X		254	
V	1.5	5.0E2	1.0	0.18		1.5			X	1.8	14.8
Ti	> 221	6.0E3	N	0.04						0.39	
Sc	< 0.29	5.3E4	N	5.5E-6						5.4E-5	
Ca	> 388	1.6E4	N	0.02						0.20	
K	> 488	N	N								
Cl	> 488	N	N								
S	> 405	N	N								
P	> 305	1.0E2	N	3.1				X		31	
Si	> 474	1.0E4	N	0.05						0.49	
Al	> 474	5.2E3	N	0.09						0.89	
Mg	> 293	6.0E3	N	0.05						0.49	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	—	—	—	—	—	—	m^3/s	m^3/s
Na	> 430	5.3E4	N	0.01						0.10	
F	> 283	2.5E3	N	0.11						1.08	
O	NR	-	-								
N	NR	N	N								
C	NR	3.5E3	N								
B	12.26	3.1E3	N	4.0E-3						0.04	
Be	< 0.02	2.0	N	0.01						0.08	
Li	4.94	22	N	0.22						2.2	
II. XAD-2 Resin Extract and Rinse											
LC1	102	1.0E2	N	1.0	2			X		9.9	
LC2	123	1.1E2	N	1.1	7			X		10.8	
LC3	121	0.02	N	6,050	23			X		59,653	
LC4	123	9.9E2	N	0.12	9					1.2	
LC5	98*	1.3E3	N	0.08	8					0.74	
LC6	862	1.7E2	N	1.1	22			X		50	
LC7	211	1.0E2	N	2.1	3			X		21	
PAH											
Acenaphthylene	1.09	N	N								
Fluorene	0.72	N	N								
Phenanthrene	3.62	1.6E3	N	0.0026						0.02	
Anthracene	2.17	5.6E3	N	3.88E-4						0.0038	
Fluoranthene	1.81	9.0E4	N	2.01E-5						1.98E-4	
Pyrene	0.72	2.3E5	N	3.13E-6						3.09E-5	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02. LEVEL 1

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN-TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN-TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/m³	µg/m³	µg/m³	—	—	—	—	—	—	m³/s	m³/s
1,2-benzanthracene	ND	45	N								
Chrysene	ND	2.2E3	N								
Benzo[e]pyrene	ND	3.0E3	N								
Benzo[g]pyrene	ND	0.02	N								
Pyrene	ND	N	N								
Indeno(1,2,3-C,D)pyrene	ND	1.6E3	N								
1,12-Benzoperylene	ND	N	N								
1,2,5,6-Dibenzanthracene	ND	0.09	N								
PCB											
as DCB	3.62	500	N	0.01						0.07	
Sb	<18	500	N	<0.04						<0.39	
As	<53	2.0	N	<26.5				X		<261	
Hg	19	50	10	0.38		1.90		X	X	3.8	18.7
SSMS											
U	<0.96	-	-								
Th	<4.58	-	-								
Bi	<0.96	4.1E2	N	<2.3E-3						<0.02	
Pb	<5.15	1.5E2	N	<0.03						<0.30	
Tl	<1.75	1.0E2	N	<0.02						<0.20	
Hg	NR	50	10								
Au	<0.96	N	N								

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	μg/m³	μg/m³	μg/m³	--	—	—	—	—	—	m³/s	m³/s
Pt	NR	2.0	N								
Ir	NR	-	-								
Os	<1.47	-	-								
Rl	NR	-	-								
W	<1.07	1.0E3	N	<1.1E-3						<0.01	
Ta	<0.96	5.0E3	N	<1.9E-4						<1.9E-3	
Hf	<2.04	5.0E2	N	<4.1E-3						<0.04	
Lu	<0.96	-	-								
Yb	<0.96	-	-								
Tm	<0.96	-	-								
Er	<1.19	-	-								
Ho	<0.96	-	-								
Dy	<0.96	9.3E2	N	<1.0E-4						<9.9E-4	
Tb	<0.96	-	-								
Gd	<0.96	-	-								
Eu	<0.96	-	-								
Sm	<2.04	5.3E4	N	<3.8E-5						<3.8E-4	
Nd	1.36	N	N								
Pr	<0.96	5.1E4	N	<1.9E-5						<1.9E-4	
Cl	<0.96	8.2E4	N	<1.2E-5						<1.2E-4	
La	<0.96	1.1E5	N	<8.7E-6						<8.6E-5	
Ba	<2.32	5.0E2	N	<4.6E-3						<0.05	
Cs	<0.96	-	-								
I	0.96	N	N								
Te	<0.96	1.0E2	N	<0.01						<0.10	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN-TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m³	μg/m³	μg/m³	—	—	—	—	—	—	m³/s	m³/s
Sb	<0.96	5.0E2	N	<1.9E-3						<0.02	
Sn	<0.96	N	N								
In	NR	1.0E2	N								
Cd	<0.96	10	N	<0.10						<1.0	
Ag	164.0	10	N	16.4				X		162	
Pd	<0.96	-	-								
Ph	<0.96	1.0	N	<1.0						<9.5	
Ru	<0.96	-	-								
Mo	<4.58	5.0E3	N	<9.2E-4						<0.01	
Nb	<0.96	2.2E4	N	<4.4E-5						<4.3E-4	
Zr	<5.15	5.0E3	N	<1.0E-3						<0.01	
Y	<0.96	1.0E3	N	<9.6E-4						<0.01	
Sr	0.85	3.1E3	N	2.7E-4						2.7E-3	
Rb	<0.96	1.2E5	N	<8.0E-6						<7.9E-5	
Br	1.36	N	N								
Se	<0.96	2.0E2	N	<4.8E-3						<0.05	
As	<0.96	2.0	N	<0.48						<4.7	
Ge	<0.96	5.6E2	N	<1.7E-3						<0.02	
Ga	<0.96	5.0E3	N	<1.9E-4						<1.9E-3	
Zn	<79.2	4.0E3	N	<0.02						<0.20	
Cu	<79.2	2.0E2	N	<0.40						<3.9	
Ni	<62.2	15	N	<4.2						<41	
Co	<1.92	50	N	<0.04						<0.39	
Fe	<23.2	1.0E2	N	<0.02						<0.20	
Mn	<17.5	5.0E3	N	<3.5E-3						<0.03	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m³	μg/m³	μg/m³	—	—	—	—	—	—	m³/s	m³/s
Cr	<21.5	1.0	N	<21.5				X		<212	
V	<0.96	5.0E2	1.0	<1.9E-3		0.96				<0.02	9.5
Ti	54.87	6.0E3	N	0.01						0.10	
Sc	<0.96	5.3E4	N	<1.8E-5						<1.8E-4	
Ca	73.54	1.6E4	N	4.6E-3						0.05	
K	<158.4	N	N								
Cl	90.50	N	N								
S	622.22	N	N								
P	<79.2	1.0E2	N	<0.79						<7.8	
Si	NR	1.0E4	N								
Al	<175.3	5.2E3	N	<0.03						<0.30	
Mg	<107.5	6.0E3	N	<0.02						<0.20	
Na	<158.4	5.3E4	N	<3.0E-3						<0.03	
F	<7.4	2.5E3	N	<2.9E-3						<0.03	
O	NR	-	-								
N	NR	N	N								
C	NR	3.5E3	N								
B	<67.88	3.1E3	N	<0.002						<0.22	
Be	<13.9	2.0	N	<7.0				X		69	
Li	<13.9	22	N	<0.63						6.2	
III. Aqueous Condensate and Impingers											
LC1	ND	100	N								
LC2	ND	110	N								
LC3	120	0.02	N	6,000	23	-		X		59,160	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (F × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m³	μg/m³	μg/m³	—	—	—	—	—	—	m³/s	m³/s
LC4	ND	990	N								
LC5	ND	1,300	N								
LC6	310	170	N	1.82	20	-		X		17.95	
LC7	170	100	N	1.7	2	-		X		16.76	
PAH											
Acenaphthylene	ND	N	N								
Fluorene	0.36	N	N								
Phenanthrene	2.90	1,600	N	0.0018						0.02	
Anthracene	ND	56,000	N								
Fluoranthene	3.62	90,000	N	4.02E-5						3.96E-4	
Pyrene	2.52	230,000	N	1.1E-5						1.08E-4	
1,12-Benzanthracene	0.22	45	N	4.89E-3						0.05	
Chrysene	ND	2,200	N								
Benzo[e]pyrene	ND	3,000	N								
Benzo[a]pyrene	ND	0.02	N								
Perylene	ND	N	N								
Indeno(1,2,3-C,D)pyrene	ND	1,600	N								
1,12-Benzoperylene	ND	N	N								
1,2,5,6-Dibenzanthracene	ND	0.09	N								
Sb	3.03	500	N	0.01		-				0.10	
As	7.18	2.0	N	3.59		-		X		35.40	
Hg	68.73	50	10	1.37		6.87		X	X	13.51	67.74

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	—	—	—	—	—	—	m^3/s	m^3/s
SSMS - U	< 0.25	-	-								
Th	< 0.29	-	-								
Bi	6.51	4.1E2	N	0.02						0.20	
Pb	95.6	1.5E2	N	0.64						6.31	
Tl	< 0.69	1.0E2	N	< 0.01						< 0.10	
Hg	NR	50	10								
Au	< 0.06	N	N								
Pt	< 0.06	2.0	N	< 0.03						< 0.30	
Ir	< 0.06	-	-								
Os	< 0.06	-	-								
Re	NR	-	-								
W	1.24	1.0E3	N	1.2E-3						0.01	
Ta	0.40	5.0E3	N	8.0E-5						8.0E-4	
Hf	< 1.2	5.0E2	N	< 2.4E-3						< 0.02	
Lu	< 0.17	-	-								
Yb	< 0.75	-	-								
Tm	< 0.20	-	-								
Er	< 0.76	-	-								
Ho	< 0.07	-	-								
Dy	< 0.21	9.3E2	N	< 2.2E-5						<2.2E-4	
Tb	< 0.07	-	-								
Gd	< 0.46	-	-								
Eu	< 0.26	-	-								
Sm	0.57	5.3E4	N	1.1E-5						1.1E-4	
Nd	< 0.49	N	N								

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree

EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m³	μg/m³	μg/m³	—	—	—	—	—	—	m³/s	m³/s
Pr	< 3.84	5.1E4	N	< 7.5E-5						< 7.4E-4	
Ce	< 0.26	8.2E4	N	< 3.2E-6						<3.2E-5	
La	< 2.99	1.1E5	N	< 2.7E-5						<2.7E-4	
Ba	2.46	5.0E2	N	4.9E-3						0.05	
Cs	< 0.06	-	-								
I	<28.6	N	N								
Tp	< 0.07	1.0E2	N	< 7.1E-4						< 0.01	
Sb	0.28	5.0E2	N	5.5E-4						0.01	
Sn	1.78	N	N								
In	NR	1.0E2	N								
Cd	< 0.28	10	N	<0.03						< 0.30	
Ag	6.09	10	N	0.61						6.01	
Pd	< 0.06	-	-								
Rh	< 0.06	1.0	N	< 0.06						< 0.59	
Ru	< 0.06	-	-								
Mo	130.1	5.0E3	N	0.03						0.30	
Nb	5.94	2.2E4	N	2.7E-4						2.7E-3	
Zr	0.29	5.0E3	N	5.8E-5						5.7E-4	
Y	0.19	1.0E3	N	1.9E-4						1.9E-3	
Sr	0.47	3.1E3	N	1.5E-4						1.5E-3	
Rb	0.27	1.2E5	N	2.3E-6						2.3E-5	
Br	234.58	N	N								
Se	0.67	2.0E2	N	3.4E-3						0.03	
As	3.87	2.0	N	1.94				X		19.13	
Ge	0.24	5.6E2	N	4.3E-4						4.2E-3	

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	—	—	—	—	—	—	m^3/s	m^3/s
Ga	0.06	5.0E3	N	1.2E-5						1.2E-4	
Zn	223.43	4.0E3	N	0.06						0.59	
Cu	325.25	2.0E2	N	1.63				X		16.07	
Ni	319.60	15	N	21.31				X		210.12	
Co	24.32	50	N	0.49						4.83	
Fe	7579.79	1.0E3	N	7.58				X		74.74	
Mn	65.05	5.0E3	N	0.01						0.10	
Cr	1527.27	1.0	N	1527.27				X		1.5E4	
V	34.82	5.0E2	1.0	0.07		38.42			X	0.69	378.82
Ti	12.78	6.0E3	N	2.1E-3						0.02	
Sc	< 0.25	5.3E4	N	< 4.8E-6						< 4.7E-5	
Ca	94.75	1.6E4	N	0.01						0.10	
K	132.93	N	N								
Cl	≥ 8.48	N	N								
S	3809.69	N	N								
P	60.24	1.0E2	N	0.60						5.92	
Si	115.96	1.0E4	N	0.01						0.10	
Al	28.85	5.2E3	N	0.01						0.10	
Mg	17.05	6.0E3	N	2.8E-3						0.03	
Na	≥ 311.1	5.3E4	N	≥ 0.01						≥ 0.10	
F	186.21	2.5E3	N	0.07						0.69	
O	NR	-	-								
N	NR	N	N								
C	NR	3.5E3	N								
B	NR	3.1E3	N								

TABLE D-7. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Braintree EFFLUENT STREAM NO

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	—	—	—	—	—	—	m^3/s	m^3/s
Be	0.25	2.0	N	0.12						1.23	
Li	<0.71	22	N	<0.03						<0.32	

TABLE D-8. ESP OUTLET WORKSHEET NOTES

NOTES

SASS Train - for each particulate fraction

$$\frac{\mu g}{m^3} = (\text{average of particulate catch, } \mu g)\ \frac{1}{3.7986 \text{ g sample}} \times 0.21487\ \frac{g}{dscm}$$

$$\text{TUDR} = (\text{degree of hazard}) \times \left(9.86\ \frac{m^3}{s}\right)$$

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

$$\text{ppm} \times \frac{MW}{22{,}400} \times 10^6 = \mu g/m^3$$

<u>or</u> $\text{ppm} \times MW \times 44.642 = \mu g/m^3$

APPENDIX E - CORRESPONDENCE DETAILING ABNORMAL INCINERATOR OPERATING CONDITIONS

50 Stanford Street Boston Massachusetts 02114
617/367-4000 TWX 710 321 6365 Cable Address: METEDD-Boston

Metcalf & Eddy, Inc.
Engineers & Planners

J-4747

December 1, 1978

Mr. Paul G. Gorman
Principal Chemical Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Subject: Braintree Municipal Incinerator

Dear Mr. Gorman:

Our November 22, 1978 letter enclosed one copy each of stack test reports for tests conducted by Air Quality Consultants under the general supervision of Metcalf & Eddy, Inc. on November 1, 1977, June 13, 1978, and August 17, 1978.

As you requested, we are writing this letter to elaborate on the mechanical problems covered briefly in the handouts during our November 8, 1978 meeting in our office. The purpose is to suggest possible abnormal operating conditions during Midwest Research Institute's (MRI) tests of January 17 to 19 inclusive, 1978, compared to the operating conditions during the previous and subsequent tests conducted by Air Quality Consultants. We explained during the meeting the circumstances under which several modifications of which we were unaware were made to the systems subsequent to the November 1, 1977 test. It was necessary to restore the integrity of the systems prior to the June 13, 1978 test. With the change of Braintree Incinerator Superintendents in this period, we are unable to determine from the plant's records the approximate dates when these modifications were made.

The following abnormal operating conditions would contribute to the high stack gas flow rates summarized in Table 4-16, page 54 of MRI's report, compared to the November 1, 1977 report for tests at similar refuse charging rates in the range of 4.5 to 5.4 tons per hour:

1. <u>Isolating Damper On Boiler No. 2 Not Closed Tightly</u>

   The operating mechanism was unsatisfactory and later replaced with an improved design. We understand that you personally viewed the blades of the damper through the inspection port to be sure that the blades were closed properly. At that time,

we believe that the only way that you could be sure of closing the damper tightly would be to use a long pipe wrench on the input shaft of the "Limitorque" operator. We have also found that it is necessary to operate with the damper partially closed and possibly increase the gas flow for a short time to purge the sealing surfaces of dust before closing tightly. The leakage through this damper would add to the measured inlet flow in the bypass duct to give the total inlet flow to Precipitator No. 2.

2. Excess Air Inleakage At Water Seals Between Residue Chutes And Water Troughs

The chutes were modified to a sliding section arrangement. The chutes are approximately 3-feet-6-inches by 7-feet-0-inches. The sliding sections were found to leak considerably and were welded solid again. The large inleakage would result in high gas flows.

3. Precipitator Inside Doors

The inside doors may not have been clamped tightly which would result in air inleakage.

4. Overfire Air

Overfire air has not been used during normal operation. The overfire air fan discharge damper does not close tightly and will be reconditioned in the future. If MRI's tests were run without having the outside air inlet blocked with plywood, excess air could not be reduced to a satisfactory value based on our observations of the other tests.

5. Gas Burner Windbox Fan

The damper on this fan does not close tightly and will be reconditioned in the future. If the blocking of the fan's inlet were not in place during MRI's tests, there would be some loss in excess air control.

6. Access Doors

The tests covered by Air Quality Consultants Reports were run with all access and inspection doors closed with the exception of the small door at the discharge end of the furnace. Based on our observations, if some doors were left open, there would be a loss in excess air control.

The following abnormal operating conditions would contribute to the high particulate concentrations summarized in Table 4-16, page 54 of MRI's Report:

7. Rotary Valve at Precipitator Hopper Outlet

Because the rotary valves needed rebuilding, at some time after the November 1, 1977 tests, the internals of the rotary valves were removed and the seal was at the residue chutes. With the leaking seals in Item 2, there could be a back-flow through the ash line which would re-entrain dust in the hopper and this dust would be discharged to the stack. During the time when the internals of the rotary valves were removed, blanking plates were added to the rotary valves. We understand that you personally observed that the rotary valve on Precipitator No. 2 had a chain and sprocket mechanism in place with the motor running. We can assume that the internals were in place. Because the rotary valves required reconditioning, the valve leakage could still be sufficient for a back-flow through the ash line which would re-entrain dust in the hopper as described above. The rotary valves were restored to proper operating condition prior to the June 13, 1978 test.

8. Ash Line From Economizer Hopper

A sluicing arrangement was installed just below the economizer hopper outlet flange. A relatively large cone-shaped distributor, connected to a water supply, was installed in the 8-inch ash line. This arrangement was removed because it caused line stoppages. We believe that proper ash removal from the economizer hopper is essential to reducing the inlet dust loading to the precipitator.

9. Precipitator Inlet Gas Distribution Plate Rapper System

The system on Precipitator No. 2 was giving trouble and may not have been operating. If some holes in the plates were plugged, gas distribution would be affected and efficiency would be lower than normal.

10. Excessive Particulate Entrainment From The Furnace

The excess air inleakage described in Item 2 would result in higher than normal particulate entrainment from the furnace. There is a certain amount of dusting at the discharge end of the stoker and this dust is carried back through the furnace by the inleakage air.

The high inlet stack gas flow rates of 37,520 acfm (actual cubic feet per minute) average (range 37,160 to 38,043 acfm) in MRI's Report exceed the precipitator's original design point of 32,000 acfm at which the expected collection efficiency is 93 percent. The expected collection efficiency at 37,520 acfm would be about 89.2

percent based on an extrapolation of the expected precipitator performance curve, copy of which we handed to you. The actual inlet gas flow to the precipitator may exceed the test inlet flow assuming inleakage through the isolating damper, as described in Item 1, thereby still further decreasing the precipitator's expected collection efficiency. The higher than normal precipitator inlet dust loading can be explained by Items 8 and 10. The re-entrainment described in Item 7 would contribute to high outlet particulates. We were interested in your comment that near the end of the tests the precipitator power was shut down to permit Southern Research Institute's personnel to remove some high voltage test leads and there was little, if any, difference in the plume. This would tend to confirm the re-entrainment described in Item 7.

We intended to discuss with you the boiler efficiencies of 66.3, 74.3, and 72.9 percent for test numbers 1, 2, and 3 respectively in Table 4-2, page 24 of MRI's Report, but ran out of time. We understand that there was no intent to run a complete efficiency test and that the computations were based on uncorrected steam flow chart readings and input based on average gross calorific value determined for refuse feed each day ("as received" basis). We suggest that the boiler efficiencies are actually considerably too high based on comprehensive tests in which we have participated of similar units and the high excess air values at which the boiler was operating. Our concern is that these boiler efficiencies may be misleading unless you include further explanation. We consider that a comprehensive efficiency test should be made by the heat-loss method wherein the various stoker-boiler heat losses are accurately determined and added to the heat output to arrive at a heat input. Subsequently, the refuse heating value in Btu-per-pound as fired would be determined utilizing the heat input as determined above and the refuse feed rate. Such a test should be conducted over at least an eight hour time span.

We enjoyed our meeting with Mr.Golembiewski and you and with Mr. Freeman of EPA, and consider the exchange of ideas and information very useful. Please let us know if you require any further information from us in preparing a compendium which we understand will be submitted to the town and the other interested parties for review.

Very truly yours,

J.P. Allen

J.P. Allen
Project Manager

JP:es
cc: Mr. M.A. Golembiewski
Mr. H.M. Freeman, EPA
Mr. J.E. O'Malley
Mr. R.R. Sherman
Mr. E.L. Courchene